Llano Estacado Regional Water Planning Group (Region O) 2011 Regional Water Plan Phase I Report

1. **Estimates of Population and Water Demands for New Ethanol Industries and Expanding Dairies;**

2. **Evaluation of Water Supplies and Desalination Costs of Dockum Aquifer Water; and**

3. **Video Conferencing Facilities Available for Coordination Between Regions A and O.**

Prepared for:

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Texas Water Development Board

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April 30, 2009

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The purposes of this study were to (1) make estimates of population and water demands for new ethanol plants and expanded numbers of dairies of the Llano Estacado Water Planning Region, (2) evaluate water supplies and desalination costs of Dockum Aquifer water, and (3) identify and describe video conferencing facilities available for coordination between Regions A and O. A summary of the results is presented below.

Ethanol Plants: In Deaf Smith, Hale, and Hockley Counties of the Llano Estacado Water Planning Region, as of 2008, three ethanol plants of 110 million gallons per year and one plant of 50 million gallons per year capacity have been constructed and either are in operation or will be in operation within a few months. These are new industries for the region, for which water supplies have not been included in previous regional water plans. The combined water requirements of these four plants are about 3.5 million gallons per day, or 3,920 acre-feet per year.

Dairies and Dairy Cattle: The number of dairies has increased from 37 in 2006 to 59 in 2008, with the estimated number of dairy cattle having increased from about 55,000 in 2005 to 130,498 head in 2008. During this period, milk production has increased from 4.14 million pounds per day in 2005 to 9.00 million pounds per day in March 2008. The projected number of head of dairy cattle in the eight-county area has been revised to 155,750 in 2010, 188,544 in 2020, and 280,714 head in 2060.

Revised projections of drinking water for dairy cattle and dairy milking parlor sanitation demands are 8,374 acre-feet per year in 2010, 11,198 acre-feet per year in 2030, and 15,093 acre-feet per year in 2060 compared to the 2006 Water Plan projection of 11,587 acre-feet per year in 2060.

The increased dairy production is projected to result in a larger number of dairy workers and their associated family members, resulting in an increased municipal water demand of 466 acre-feet per year for the increased population of 2,405 in 2010, increased municipal demand of 182 acre-feet per year in 2020, and for 2060 an increased demand of 769 acre-feet per year for the increased projected population of 4,255.

The irrigation water requirements for feed production for the revised dairy projections are 16,938 acre-feet per year higher in 2010, 20,504 acre-feet per year higher in 2020, 25,019 acre-feet per year higher in 2040, and 30,528 acre-feet per year higher in 2060.

Increased Demand for Water for Ethanol Plants, Dairies, and Associated Population: The total increased water demand for ethanol production, dairies, dairy population and dairy feed production is 23,362 acre-feet per year in 2010, of which 16.7 percent is for ethanol production, 8.7 percent is for dairies, 2.0 percent is for dairy worker population, and 72.5 percent is for dairy feed production. The total is 30,166 acre-feet per year in 2040, and 38,723 acre-feet per year in 2060, of which ethanol production is 10.1 percent, dairies are 9.1 percent, dairy worker population is 1.98 percent, and dairy feed production is 78.8 percent.

Water Supply Potentials and Estimated Costs of Water from the Dockum Aquifer: The Dockum Aquifer is a potential source of additional water in Bailey, Castro, Deaf Smith, Hale, and Parmer Counties. Dockum wells in the vicinity of Hereford and in northeast Castro County typically are 800-950 ft deep. The deepest well depths would be about 1,400 ft in Lamb County. Typical well yields of Dockum wells is estimated to range from about 400 gpm in Deaf Smith County area to about 200 gpm in the southern part of the study area. The salinity of water in the Deaf Smith County area typically ranges from concentrations of 800 to 1,500 milligrams per liter of total dissolved solids. In southern part of the study area, the salinity is greater than 20,000 mg/L of total dissolved solids.

Potential well field designs were prepared for two well fields and at three pumping rates (0.2, 1, 3, and 10 million gallons per day (MGD). The most economical water supply, not considering water treatment, was from the Deaf Smith well field pumping at a rate of 3 MGD. The delivery of raw water to a terminal near the well field is estimated to cost about $305 per acre foot.

Estimated Costs of Water from the Dockum Aquifer: Costs were estimated to obtain and desalt raw water from the Dockum Aquifer, and to dispose to concentrates resulting from desalination. Costs were estimated for desalination using Reverse Osmosis (RO) and concentrate disposal using solar evaporation and deep well injection for 0.2 MGD, 1 MGD, 3 MGD, and 10 MGD sized Dockum Aquifer well fields having 1,500, 3,000, 5,000, and 20,000 mg/L concentrations of TDS. Estimated total costs for raw water, desalination, and concentrate disposal for water from the Dockum Aquifer with TDS of 1,500 mg/L range from $5.35 per 1,000 gallons for a 0.2 MGD size facility, to $3.76 per 1,000 gallons for a 1 MGD facility, to $2.75 per 1,000 gallons for a 3 MGD facility, and $2.29 per 1,000 gallons for a 10 MGD facility. Estimated total costs for raw water, desalination, and concentrate disposal for water from the Dockum Aquifer with TDS of 3,000 mg/L range from $6.65 per 1,000 gallons for a 0.2 MGD size facility, to $4.77 per 1,000 gallons for a 1 MGD facility, to $3.07 per 1,000 gallons for a 3 MGD facility, and $2.61 per 1,000 gallons for a 10 MGD facility. Estimated total costs for raw water, desalination, and concentrate disposal for water from the Dockum Aquifer with TDS of 5,000 mg/L range from $7.94 per 1,000 gallons for a 0.2 MGD size facility, to $5.57 per 1,000 gallons for a 1 MGD facility, to $4.08 per 1,000 gallons for a 3 MGD facility, and $3.23 per 1,000 gallons for a 10 MGD facility. Estimated total costs for raw water, desalination, and concentrate disposal for water from the Dockum Aquifer with TDS of 20,000 mg/L range from $11.44 per 1,000 gallons for a 0.2 MGD size facility, to $7.21 per 1,000 gallons for a 1 MGD facility, to $5.62 per 1,000 gallons for a 3 MGD facility, and $5.10 per 1,000 gallons for a 10 MGD facility.

Interactive Video Conferencing Facilities: Interactive Video Conferencing Services needed by Regions A and O include, (1) video conferencing equipped meeting rooms located conveniently to each regional water planning group, and (2) staffing to operate the conferencing equipment. Fully staffed interactive video conferencing facilities and services, with capabilities to meet the needs of Regions A and O are in existence and are available to both Regions A and O at Offices of the AgriLife Research Facilities of the Texas A&M University System in Amarillo and Lubbock, respectively. Consequently it appears that justification can not be made at this time for the purchase and installation of such facilities.

Conclusions: The revised projections of water demand for the ethanol and expanded dairy water using sectors, the Dockum Aquifer water supply analyses, and the description of available interactive video conferencing facilities presented in this report are available for use in development of the 2011 Llano Estacado Regional Water.

Section 1
Background, Introduction, Objectives, Methods, and Data

1.1 Background and Introduction

By early 2008, two (2) 110 million gallons per year capacity ethanol production plants had been constructed in Deaf Smith County, one (1) 110 million gallons of ethanol production capacity per year plant had been constructed in Hockley County, and a 40 million gallons per year plant had been located in Hale County of the Llano Estacado Water Planning Region (Region O). In addition, there are regular announcements of new dairies being located in Bailey, Castro, Deaf Smith, Hale, Hockley, Lamb, Lubbock, Parmer, and Terry Counties. These are new industries for the region for which water supplies were not included in previous regional water plans for either of these water using enterprises, the population that will supply the labor, or the input support industries, including irrigation water for the production of grain and forage crops to supply raw materials to either or both of these new and in the case of dairies, expanded sectors.

In view of the fact that some municipal water supplies are obtained from areas of Region A to meet projected municipal needs in Region O, it is essential that the Llano Estacado Regional Water Planning Group (Region O) and Panhandle Regional Water Planning Group (Region A) coordinate and communicate regional water planning activities and work. In order to more efficiently accomplish necessary coordination, it is proposed that interactive video conferencing methods and facilities be evaluated as a means of facilitating coordination meetings of Regions A and O.

The purposes of this Region O 2011 Regional Water Planning Phase I study are related to develop estimates of water demands for the new ethanol and dairy water users, to evaluate potential sources of water supply from the Dockum Aquifer of the six county area, and to evaluate interactive video conferencing as a mean to facilitate interregional coordination.

1.2 Objectives

The specific objectives are as follows:

a. Estimate additional quantities of water demand (manufacturing and dairy water demand) for operation of the new ethanol plants, dairies, and supporting manufacturing establishments of Bailey, Castro, Deaf Smith, Hale, Hockley, Lamb, Lubbock, Parmer, and Terry Counties, with projections by decade from 2010 to 2060, and provide increased total for Region O;[1]

b. Estimate additional population in Bailey, Castro, Deaf Smith, Hale, Hockley, Lamb, Lubbock, Parmer, and Terry Counties, including cities of each county, with projections by decade from 2010 to 2060, and provide increased total for Region O, resulting from new employment opportunities from the ethanol and dairy expansions;
c. Estimate additional quantities of municipal water needed to meet the needs of additional population of Bailey, Castro, Deaf Smith, Hale, Hockley, Lamb, Lubbock, Parmer, and Terry Counties, including cities of each county, with projections by decade from 2010 to 2060, and provide increased total for Region O;
d. Estimate additional quantities of irrigation water demand for production of crops to supply inputs (grain and forage) to the new ethanol plants and additional dairies in Bailey, Castro, Deaf Smith, Hale, Hockley, Lamb, Lubbock, Parmer, and Terry Counties with projections by decade from 2010 to 2060, and provide increased total for Region O; and
e. Compute total of estimates, with projections from 2010 to 2060, of additional municipal, manufacturing, livestock and dairies, irrigation water demand in Bailey, Castro, Deaf Smith, Hale, Hockley, Lamb, Lubbock, Parmer, and Terry Counties, with projections by decade from 2010 to 2060, and provide increased total for Region O.
f. Estimate groundwater availability from the Dockum Aquifer in the six county area on the basis of (i) information compiled by the team preparing the Dockum GAM, and (ii) TWDB Report 359, “The Groundwater Resources of the Dockum Aquifer in Texas;”
g. Estimate numbers and costs to drill and equip wells in the Dockum Formation to meet projected municipal, manufacturing, livestock, and irrigation needs;
h. Estimate salinity of Dockum groundwater and select desalination process;
i. Estimate costs to desalt water from the Dockum for
    1. Salinity levels ranging from 1,500 ppm to 5,000 ppm of TDS (Total Dissolved Solids) and dispose of brine concentrate, and
    2. Desalt plant capacities of 0.2 MGD, 1 MGD, 3 MGD, and 10 MGD;
j. Estimate environmental effects of Water Management Strategies using Dockum Aquifer Water to meet increased water demand,
k. Identify and describe Interactive Video Conferencing Services needed by Regions A and O for coordination of regional water planning:
    1. Identify existing Interactive Video Conferencing Facilities/Services located conveniently to members of the Regions A and O Regional Planning Groups, including costs of such services, if available;
    2. Estimate costs of establishing and operating Interactive Video Conferencing Facilities/Services to meet the needs of Regions A and O; and

[1] During the data collection effort it was found that an ethanol plant had been located in Hockley County, and representatives of the dairy sector included information for Lubbock and Terry Counties, therefore, the study area was expanded to include these counties.

l. Present comparison of costs and services of Interactive Video Conferencing Facilities available from others and via establishment of specialized services for the Regional Planning Groups.

1.3 Methods and Data

The methods of analyses used are as specified in TWDB Water Planning Rules and Guidelines, including quantities of water needed during drought of record conditions, costs of water using prices as specified in the Guidelines (Second Quarter 2007 prices or other price date if specified), and environmental effects of water management strategies to meet projected water needs.

Sources of data regarding population changes will be the Texas State Data Center, information about changes in employment in the counties, and manufacturing and business establishment plant specific information, as available. Per capita water use will be obtained from the TWDB water use reports for municipal water users of the region, and from manufacturing water needs for each new manufacturing plant to be located within the area. The latter to be obtained from representatives of the ethanol industry, where available, and will be estimated from similar types of water using activities, if needed. In the case of dairy water use, parameters of the 2006 Llano Estacado Regional Water Plan will be reviewed, and adjusted, if needed, using data from representatives of dairy water users. Report 359, "The Groundwater Resources of the Dockum Aquifer in Texas," will be a primary source of information for developing water management strategies from the Dockum Aquifer.

Section 2
Population and Water Demand
Executive Summary

In the 2006 Llano Estacado Regional Water Plan, there was no provision for water for the operation of ethanol plants, since there were no such plants located in the region at the time the regional water plan was being developed, and there were no projections that such plants would be located in the region during the 50-year planning period. However, in Deaf Smith, Hale, and Hockley Counties of the Llano Estacado Water Planning Region, as of 2008, three ethanol plants of 110 million gallons production capacity per year and one plant of 50 million gallons per year capacity have been constructed and either are in operation or will be in operation within a few months. The combined water requirements of these four plants are about 3.5 million gallons per day, or 3,920 acre-feet per year.

In the 2006 Regional Water Plan, dairy cattle numbers in Bailey, Castro, Deaf Smith, Hale, Lamb, Parmer, Lubbock, and Terry Counties were about 14,900 head in year 2000, and were projected at 87,018 in 2010, reaching a maximum of 159,133 in 2020. However, during the period of 2005 through 2007, the dairy industry of Bailey, Castro, Deaf Smith, Hale, Lamb, and Parmer Counties has increased significantly. The number of dairies has grown from 37 to 59, and the estimated number of dairy cattle has increased from about 55,000 in 2005 to 130,498 head in 2008, with milk production increasing from 4.14 million pounds per day in 2005 to 9.00 million pounds per day in March 2008. The projected number of head of dairy cattle in the eight-county area has been revised to 155,750 in 2010, 188,544 in 2020, and 280,714 head in 2060.

Drinking water demands for dairy cattle and dairy milking parlor sanitation were based upon 48 gallons per cow per day instead of the 65 gallons per cow per day of the 2006 Regional Water Plan. The revised projections show an increase from quantities of the 2006 Regional Water Plan of about 6,256 acre-feet per year in 2010, lower quantities of water demand for these purposes for the period of 2017 through 2033 (1,449 acre-feet per year less in 2020), and 15,093 acre-feet per year more in 2060 than was projected for the 2006 Regional Water Plan.

The increased dairy production is projected to result in a larger population due to more dairy workers, resulting in an increased municipal water demand of 466 acre-feet per year in 2010, an increased demand of 182 acre-feet per year in 2020, and for 2060 an increased municipal demand of 769 acre-feet per year.

The increased irrigation water requirements for feed production for the revised dairy projections, in comparison to irrigation requirements for traditional cropping patterns are 16,938 acre-feet per year in 2010, 20,504 acre-feet per year in 2020, 25,019 acre-feet per year in 2040, and 30,528 acre-feet per year in 2060.

The total increased water demand for ethanol production, dairies, dairy population and dairy feed production is 23,362 acre-feet per year in 2010, 30,166 acre-feet per year in 2040, and 38,723 acre-feet per year in 2060.

Introduction

During the months immediately following the completion and adoption of the 2006 Llano Estacado Regional Water Plan the Llano Estacado Regional Water Planning Group (LERWPG) became informed about the appearance of the ethanol industry, a completely new economic enterprise within the Llano Estacado Water Planning Region (Region O), and an unexpected increase in the dairy sector. Since there had not been any consideration given in the 2006 Regional Water Plan for water for ethanol production, and since that which had been given to the water needs of the dairy sector is clearly inadequate for this rapidly growing sector, it was decided to compute: (1) estimates of the growth of these two water using-sectors, (2) the effects of this growth upon the size of the population, and (3) the quantities of additional water needed by these sectors, the associated population, and related support sectors of the ethanol and dairy sectors. The estimates are presented below.

2.1 The Ethanol Sector

In the 2006 Regional Water Plan, water for ethanol production was not included, since there were no ethanol plants located in the region. As of the date of this report, three 110 million gallons per year and one 50 million gallons per year production capacity ethanol distilling plants have been constructed, and either are in operation, or will be in operation within a few months. Two of the 110 million gallons per year plants are located at Hereford in Deaf Smith County, one 110 million gallons per year plant is located near Levelland in Hockley County, and the 50 million gallons per year plant is located near Plainview in Hale County. According to an ethanol industry representative, water requirements for these ethanol plants are as follows: the 110 million gallons per year plants need 1.0 MGD (million gallons per day) and the 50 million gallons per year plant needs 0.5 MGD of fresh water for operation.[1] Thus, the water demands for these plants amount to an annual increased in manufacturing water demands in Deaf Smith County of 2,240 acre-feet per year, in Hockley County of 1,120 acre-feet per year, and in Hale County of 560 acre-feet per year, bringing the total increased manufacturing demand in the study area to 3,920 acre-feet per year.

[1] Personal interview with Mr. Tim Snyder.

With respect to effects of the ethanol plants upon demands for feedstock (corn, grain sorghum, and other crops) that would affect demand for irrigation water, representatives of the ethanol industry have indicated that the plants located at Hereford will be importing 100 percent of the grain (corn) to be used in the production process, and will not be obtaining grain feedstock from local sources.[2] The plants located at Levelland and Plainview are reported to be using a mixture of imported corn and locally produced grain sorghum, depending upon availability of grain sorghum. However, the industry is not expected to increase the number of ethanol plants in the foreseeable future, since the railway capacity to transport grain to the area will have been reached when the present plants are in operation, and railway industry representatives have informed the industry that there are no plans to increase rail capacity for these purposes. Thus, the estimated increased demand for manufacturing water is projected at 3,920 acre-feet per year through 2060, with 2,240 acre-feet per year in Deaf Smith county, 1,120 acre-feet per year in Hockley County, and 560 acre-feet per year in Hale County. The increased demand for grain for ethanol production is projected to result in a shift of irrigation water use from other crops into grain production, but since the available supplies of irrigation water are already being used; i.e.; there are irrigation water shortages in the counties affected, there is no net projected increase in irrigation water demand for these purposes.

With respect to labor, ethanol industry representatives indicated that each plant has 60 full time jobs, of which one-half or 30 will be new arrivals from outside the region and one-half, or 30 will be local hires. Thus, it is estimated that the new ethanol plants will have no appreciable effect upon the populations of the counties in which they are located, since recent population information from the Texas State Data Center indicates that the populations of the study area counties have continued to decrease in larger numbers annually than are represented by the employment potentials of the ethanol plants.

[2] Even though corn is to be imported to the region for ethanol production, the increased national demand for corn for ethanol production has driven the price of corn up, and Region O irrigation farmers are responding by increasing the production of corn by transferring acreages of other irrigated crops into corn production.

2.2 The Dairy Sector

2.2.1 Revised Estimates and Projections of Numbers of Dairy Cattle, and Dairy Water Demand

In the 2006 Llano Estacado Regional Water Plan, the numbers of dairy cattle in the Bailey, Castro, Deaf Smith, Hale, Lamb, Parmer, Lubbock, and Terry County area were 14,899 in year 2000 and were projected to be 87,018 in 2010, growing to 159,133 in 2020, and remaining at the 2020 level through 2060 (Table 2.2-1 and Figure 2.2-1).[3] Projected water requirements for dairy uses (drinking water for milking and dry cows and replacement heifers, plus sanitation at milking parlors) were projected to increase from 1,085 acre-feet per year in 2000 to 6,336 acre-feet per year in 2010, to 11,587 acre-feet per year in 2020, and remain at that level through 2060 (Table2.2-1). However, due to the trend of increased milk production, as reported to the Milk Market Administrator, the numbers of dairy cattle and the quantities of water demand of the 2006 Regional Water Plan are too low (Table 2.2-2). For example, in January of 2005, the total number of dairies in the six county area for which data are available (Bailey, Castro, Deaf Smith, Hale, Lamb, and Parmer) was 37, with average daily milk production of 4.14 million pounds (Table 2.2-2). By January of 2006, there were 44 dairies, with average daily milk production of 5.52 million pounds, and by March of 2008, there were 59 dairies with average daily milk production reported at 9.01 million pounds (Table 2.2-2). During the period from January 2005 through March 2008, the number of dairies increased from 37 to 59, or about 60 percent, while average daily milk production increased from 4.14 million pounds to 9.01 million pounds, or about 117 percent. Production in Bailey County increased by 117 percent, production in Castro County increased by 86 percent, production in Deaf Smith County increased by 238 percent, with Hale County having a 23 percent increase, Lamb County increased by 41 percent, and Parmer County increased by 315 percent. Due to the extremely rapid growth milk production since year 2005, it is clear that the numbers of head of dairy cattle and the projected dairy sector water demands of the 2006 Regional Water Plan are too low and will be revised in this study, as is explained below.

[3] The Scope of Work for this report has been expanded to include Lubbock and Terry Counties, since the Texas Association of Dairymen provided information for these counties along with information for Bailey, Castro, Deaf Smith, Hale, Lamb, and Parmer Counties.

Table 2.2-1.
Projected Number of Head of Dairy Cattle and Projected Water Requirements for Dairy Cattle as Included in the 2006 Llano Estacado Regional Water Plan

No.*	County	Total in 1990 No. Head	Total in 2000 No. Head	Projections 2010 No. Head	2020 No. Head	2030 No. Head	2040 No. Head	2050 No. Head	2060 No. Head
1	Bailey	3,000	3,200	15,095	26,991	26,991	26,991	26,991	26,991
3	Castro	1,238	2,000	15,326	28,651	28,651	28,651	28,651	28,651
7	Deaf Smith	1,869	500	15,529	30,558	30,558	30,558	30,558	30,558
12	Hale	0	400	5,374	10,347	10,347	10,347	10,347	10,347
14	Lamb	1,214	8,400	21,309	34,218	34,218	34,218	34,218	34,218
18	Parmer	1,047	400	13,292	26,183	26,183	26,183	26,183	26,183
15	Lubbock	0	0	0	0	0	0	0	0
20	Terry	0	0	1,092	2,185	2,185	2,185	2,185	2,185
	Total	8,368	14,899	87,018	159,133	159,133	159,133	159,133	159,133

No.*	County	Quantity of Water Demand for Dairy Uses (Drinking Water for Cattle and Milking Parlors)** 1990 (acft)	2000 (acft)	2010 (acft)	2020 (acft)	2030 (acft)	2040 (acft)	2050 (acft)	2060 (acft)
1	Bailey	252	233	1,099	1,965	1,965	1,965	1,965	1,965
3	Castro	104	146	1,116	2,086	2,086	2,086	2,086	2,086
7	Deaf Smith	157	36	1,131	2,225	2,225	2,225	2,225	2,225
12	Hale	0	29	391	753	753	753	753	753
14	Lamb	102	612	1,552	2,491	2,491	2,491	2,491	2,491
18	Parmer	88	29	968	1,906	1,906	1,906	1,906	1,906
15	Lubbock	0	0	0	0	0	0	0	0
20	Terry	0	0	80	159	159	159	159	159
	Total	703	1,085	6,336	11,587	11,587	11,587	11,587	11,587

* County number as listed in 2006 Regional Water Plan.
* * Calculated at 65 gallons per head per day.

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Since there are no official reports of numbers of dairy cattle nor quantities of water used by dairies, it is necessary to estimate both the numbers of head of dairy cattle and quantities of water used by dairies.[4] The Texas Association of Dairymen, in cooperation with Dr. Ellen Jordan (Professor and Extension Dairy Specialist, Texas A&M Center, Dallas, Texas), through the LERWPG Dairy Committee provided information about dairies in the study area counties of the Llano Estacado Water

[4] In October of 2007, the number of head of dairy cattle permitted by the Texas Commission on Environmental Quality (TCEQ) for the six county area of Bailey, Castro, Deaf Smith, Hale, Lamb, and Parmer was approximately 1,026,630, and according to representatives of TCEQ has been increasing at approximately one (1) percent per month. However, representatives of the Texas Association of Dairymen have advised the LERWPG that many of these permits are based upon speculation, and that market conditions will not support the implementation of dairies to the extent of the TCEQ permitted numbers.

Table 2.2-2.
Reported Number of Dairies and Average Daily Milk Production for the Months of January 2005, January 2006, January 2007, and March 2008

No.*	County	January-05		January-06		January-07		March-08	
		Number of Dairies	Pounds of Milk Per Day	Number of Dairies	Pounds of Milk Per Day	Number of Dairies	Pounds of Milk Per Day	Number of Dairies	Pounds of Milk Per Day
1	Bailey	7	481,903	8	816,287	8	842,490	9	1,097,860
3	Castro	8	875,653	8	942,755	10	1,118,569	10	1,630,348
7	Deaf Smith	5	539,745	8	1,176,377	11	1,337,021	13	1,826,393
12	Hale	4	792,021	5	894,767	6	802,108	5	973,863
14	Lamb	8	922,295	9	1,001,092	9	1,061,223	9	1,300,829
18	Parmer	5	524,298	6	690,714	10	1,099,465	13	2,178,341
15	Lubbock	NA	NA	NA	NA	NA	NA	NA	NA
20	Terry	NA	NA	NA	NA	NA	NA	NA	NA
	Total	37	4,135,915	44	5,521,992	54	6,260,876	59	9,007,633

* County number as listed in 2006 Regional Water Plan.
Source: Milk Market Administrator, AMS, Dairy Programs, US Department of Agriculture, Carrollton, Texas, December, 2007.
NA Means not available.

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Planning Region (Appendix).[5] The estimated number of dairy cows in 2008 in the eight county area is 130,498, and is projected to be 155, 750 in 2010, 188,544 in 2020, 230,060 in 2040, and 280,716 in 2060 (Table 2.2-3 and Figure 2.2-1). Castro, Deaf Smith, and Parmer Counties have the largest numbers per county in 2008 at 23,082, 26,800, and 30,491 head, respectively, and are projected to grow to 53,152, 50,621, and 56,577 head, respectively by 2060 (Table 2.2-3). Bailey, Hale, and Lamb Counties have numbers in 2008 of 15,218, 13,531, and 17,876 head, respectively, growing to 47,822, 26,576, and 38,710 head, respectively in 2060 (Table 2.2-3). Lubbock and Terry Counties have numbers in the 1,500 to 2,000 head range in 2008, growing to 3,110 and 4,146 head in 2060 (Table 2.2-3 and Figure 2.2-1).

Based upon 2008 data, the projected numbers of dairy cows for the eight county area is 68,732 head greater for 2010 than was included in the 2006 Regional Water Plan, is 29,411 read greater in 2020, 70,926 head greater in 2040, and is 121,581 head greater in 2060 (Table 2.2-4 and figure 2.2-1). The projected dairy cow numbers are greater for

[5] Letter of April 28, 2008 from Mr. John Cowan, Executive Director, Texas Association of Dairymen to the LERWPG Dairy Committee, whose membership included Dr. Melanie Barnes, Ch., Dr. Don Ethridge, Mr. Bob Josserand, and Mr. Ben Weinheimer. The information provided included numbers of dairy cattle, projected rates of growth of dairy cattle numbers, and water requirements for drinking, sanitation, and forage production for the dairy industry.

Table 2.2-3.
Projected Numbers of Dairy Cows and Replacement Heifers for Bailey, Castro, Deaf Smith, Hale, Lamb, Parmer, Lubbock, and Terry Counties (2008 Revised)

No.*	County	Estimated Total Dairy Cattle 2008 (head)[1]	Projected Numbers of Dairy Cattle[1] 2010 (head)	2020 (head)	2030 (head)	2040 (head)	2050 (head)	2060 (head)
1	Bailey	15,218	24,700	32,120	35,480	39,193	43,293	47,822
3	Castro	23,082	27,450	35,700	39,435	43,561	48,118	53,152
7	Deaf Smith	26,800	29,000	34,000	37,557	41,486	45,827	50,621
12	Hale	13,531	15,900	17,850	19,718	21,780	24,059	26,576
14	Lamb	17,876	24,000	26,000	28,720	31,725	35,044	38,710
18	Parmer	30,491	31,000	38,000	41,976	46,367	51,218	56,577
15	Lubbock	1,500	1,600	2,089	2,308	2,549	2,816	3,110
20	Terry	2,000	2,100	2,785	3,076	3,398	3,754	4,146
	Total	130,498	155,750	188,544	208,270	230,059	254,129	280,714

* County number as listed in 2006 Regional Water Plan.

[1] Data from Federal Milk Market Administration and industry Cooperative Marketing Analysis, with projections of growth from 2008 to 2010 at 9.24 percent per year, from 2010 to 2020 at 1.9 percent per year, and from 2020 to 2060 at 1.00 percent per year. <><><><>

Figure 2.2-1: Projected Numbers of Head of Dairy Cattle

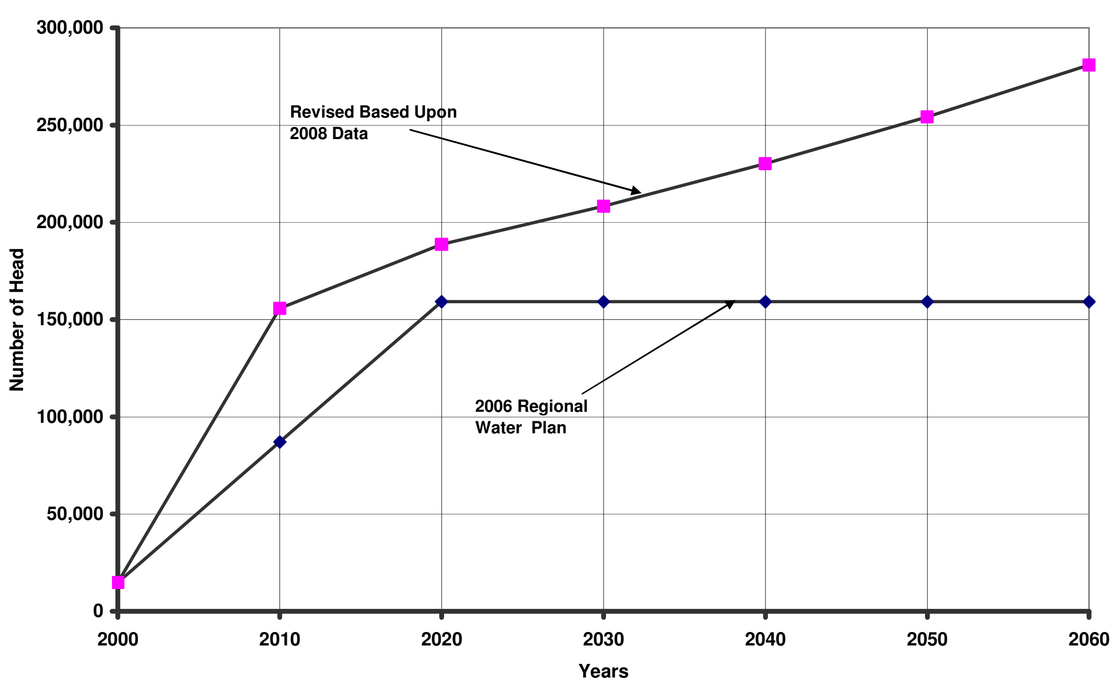


Table 2.2-4.
Projected Increased Numbers of Dairy Cattle (Cows and Replacement Heifers) for Bailey, Castro, Deaf Smith, Hale, Lamb, Parmer, Lubbock, and Terry Counties (Differences between 2008 Revised and 2006 Regional Water Plan Projections)

No.*	County	Increased Projections of Dairy Cattle over 2006 Regional Water Plan					
		2010 (head)	2020 (head)	2030 (head)	2040 (head)	2050 (head)	2060 (head)
1	Bailey	9,605	5,129	8,489	12,202	16,302	20,831
3	Castro	12,124	7,049	10,784	14,910	19,467	24,501
7	Deaf Smith	13,471	3,442	6,999	10,928	15,269	20,063
12	Hale	10,526	7,503	9,371	11,433	13,712	16,229
14	Lamb	2,691	-8,218	-5,498	-2,493	826	4,492
18	Parmer	17,708	11,817	15,793	20,184	25,035	30,394
15	Lubbock	1,600	2,089	2,308	2,549	2,816	3,110
20	Terry	1,008	600	891	1,213	1,569	1,961
	Total	68,732	29,411	49,137	70,926	94,996	121,581

* County number as listed in 2006 Regional Water Plan. <><><><><>

each projection date for each county except for Lamb County for 2020, 2030, and 2040 (Table 2.2-4).

Water demands for dairies (drinking water for dairy cattle plus water for sanitation) for the eight-county area are projected to increase from 7,016 acre-feet per

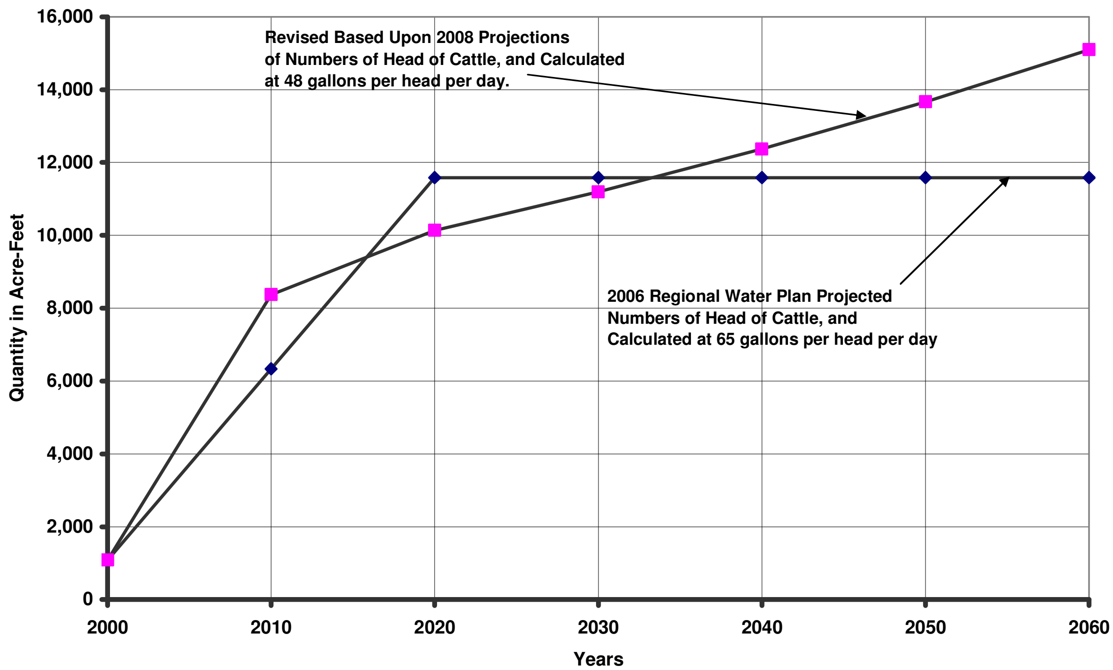
Table 2.2-5.
Projected Water Demands for Dairies of Bailey, Castro, Deaf Smith, Hale, Lamb, Parmer, Lubbock, and Terry Counties (2008 Revised)

No.*	County	Estimated Total Dairy Water Use 2008 (acft)	Projected Dairy Water Demands[1]					
			2010 (acft)	2020 (acft)	2030 (acft)	2040 (acft)	2050 (acft)	2060 (acft)
1	Bailey	818	1,328	1,727	1,908	2,107	2,328	2,571
3	Castro	1,241	1,476	1,919	2,120	2,342	2,587	2,858
7	Deaf Smith	1,441	1,559	1,828	2,019	2,231	2,464	2,722
12	Hale	728	855	960	1,060	1,171	1,294	1,429
14	Lamb	961	1,290	1,398	1,544	1,706	1,884	2,081
18	Parmer	1,639	1,667	2,043	2,257	2,493	2,754	3,042
15	Lubbock	81	86	112	124	137	151	167
20	Terry	108	113	150	165	183	202	223
	Total	7,016	8,374	10,137	11,198	12,370	13,664	15,093

* County number as listed in 2006 Regional Water Plan.
[1] Calculated at 48 gallons per head per day. Source of data is Texas Dairy Association; see footnote 5.
<><><><><>

year in 2008, to 8,374 acre-feet per year in 2010, to 10,137 acre-feet per year in 2020, to 12,370 acre-feet per year in 2040, and to 15,093 acre-feet per year in 2060 (Table 2.2-5 and Figure 2.2-2). In comparison to the 2006 Regional Water Plan projections of dairy water demand, the 2008 updated projections are based upon a larger number of head of dairy cattle in all counties of the study area except Lamb County, as mentioned above,

Figure 2.2-2: Projected Dairy Water Demand



the quantity of water use per cow per day for the revised 2008 projections is 48 gallons per head per day, while the 2006 Regional Water Plan dairy water demand projections were calculated at 65 gallons per head per day. Thus, the results shown in figure 2.2-2 show higher water demands from year 2000 through about 2017, lower total demands from 2017 through about 2033, and higher demands thereafter (Figure 2.2-2 and Table 2.2-6); i.e.; the increased numbers of head of cattle do not completely offset the lowering of the per head per day of water demand from 65 gallons to 48 gallons, as is shown in Figure 2.2-2 and Table 2.2-6. Thus, the total projected water demand for dairies in 2010 is 2,038 acre-feet per year greater than was included in the 2006 Regional Water Plan, but is 1,449 acre-feet per year less in 2020, 388 acre-feet per year less in 2030, and 3,507 acre-feet per year greater in 2060 (Table 2.2-6 and Figure 2.2-2). The reader can see the differences for each county in Table 2.2-6.

Table 2.2-6.
Differences between 2008 Revised Water Demand Projections and 2006 Regional Water Plan Projections of Dairy Water Demand for Bailey, Castro, Deaf Smith, Hale, Lamb, Parmer, Lubbock, and Terry Counties

		Difference Between 2008 Revised Dairy Water Demand Projections and Projections of Dairy Water Demands of the 2006 Regional Water Plan					
No.*	County	2010 (acft)	2020 (acft)	2030 (acft)	2040 (acft)	2050 (acft)	2060 (acft)
1	Bailey	229	-238	-58	142	363	606
3	Castro	360	-167	34	256	501	772
7	Deaf Smith	429	-397	-206	6	239	497
12	Hale	464	206	307	418	540	676
14	Lamb	-261	-1,093	-947	-786	-607	-410
18	Parmer	699	137	351	587	847	1,136
15	Lubbock	86	112	124	137	151	167
20	Terry	33	-9	6	24	43	64
	Total	2,038	-1,449	-388	783	2,077	3,507

* County number as listed in 2006 Regional Water Plan. <><><>

2.2.2 Estimates and Projections of Numbers of Dairy Workers and Dairy Worker Associated Population

Projections of population resulting from the projected growth of dairies of the area are based upon the following estimates and assumptions:

- Projected number of dairy workers is calculated at one worker per 100 projected head of dairy cattle; and
- Projected population associated with dairy workers is based upon 3.5 persons per household.

The estimated number of dairy workers in the study area in 2000 referenced in the 2006 Regional Water Plan is 149, and was projected at 870 in 2010, and at 1,591 workers in 2020 through 2060 (Table 2.2-7). For the revised projections of the increased dairy production, the estimated number of dairy workers in 2008 is 1,305, is projected at 1,558 in 2010, 1,885 in 2020, 2,301 in 2040, and 2,807 in 2060 (Table 2.2-7 and Figure 2.2-3). The increased projections of dairy production over the level included in the 2006 regional Water Plan

Table 2.2-7.
Comparison of Projected Number of Dairy Workers of 2006 Regional Water Plan with Projected Number of Dairy Workers for Increased Dairy Production (2008 Revisions) for Bailey, Castro, Deaf Smith, Hale, Lamb, Parmer, Lubbock and Terry Counties

No.*	County	2000 (number)	2006 Regional Water Plan Projected Number of Dairy Workers 2010 (number)	2020 (number)	2030 (number)	2040 (number)	2050 (number)	2060 (number)
1	Bailey	32	151	270	270	270	270	270
3	Castro	20	153	287	287	287	287	287
7	Deaf Smith	5	155	306	306	306	306	306
12	Hale	4	54	103	103	103	103	103
14	Lamb	84	213	342	342	342	342	342
18	Parmer	4	133	262	262	262	262	262
15	Lubbock	0	0	0	0	0	0	0
20	Terry	0	11	22	22	22	22	22
	Total	149	870	1,591	1,591	1,591	1,591	1,591

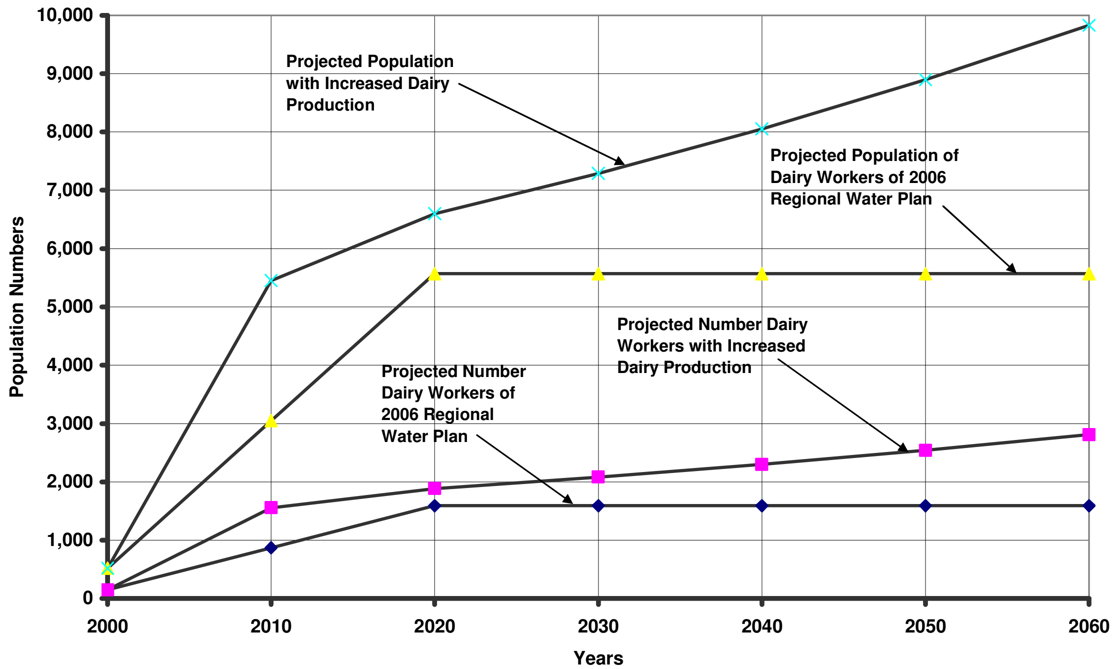
No.*	County	2008	2008 Revised Projected Total Number of Dairy Workers 2010 (number)	2020 (number)	2030 (number)	2040 (number)	2050 (number)	2060 (number)
1	Bailey	152	247	321	355	392	433	478
3	Castro	231	275	357	394	436	481	532
7	Deaf Smith	268	290	340	376	415	458	506
12	Hale	135	159	179	197	218	241	266
14	Lamb	179	240	260	287	317	350	387
18	Parmer	305	310	380	420	464	512	566
15	Lubbock	15	16	21	23	25	28	31
20	Terry	20	21	28	31	34	38	41
	Total	1,305	1,558	1,885	2,083	2,301	2,541	2,807

No.*	County	Projected Increased in Number of Dairy Workers above 2006 Regional Water Plan 2010 (number)	2020 (number)	2030 (number)	2040 (number)	2050 (number)	2060 (number)
1	Bailey	96	51	85	122	163	208
3	Castro	121	70	108	149	195	245
7	Deaf Smith	135	34	70	109	153	201
12	Hale	105	75	94	114	137	162
14	Lamb	27	-82	-55	-25	8	45
18	Parmer	177	118	158	202	250	304
15	Lubbock	16	21	23	25	28	31
20	Terry	10	6	9	12	16	19
	Total	687	294	491	709	950	1,216

* County number as listed in 2006 Regional Water Plan. <><><><><>

results in an increase in projected numbers of dairy workers of 687 in 2010, 294 in 2020, 2,310 in 2040, and 2,807 in 2060 (Table 2.2-7 and Figure 2.2-3).

Figure 2.2-3: Projected Numbers of Dairy Workers and Associated Population



At 3.5 persons per household, the size of the dairy worker and dairy worker associated population of the 2006 Regional Water Plan was estimated at 3,046 in 2010, and 5,570 from 2020 to 2060 (Table 2.2-8 and Figure 2.2-3). For the revised projections of dairy production, the dairy workers and associated population was projected at 5,451 in 2010, 6,559 in 2020, 8,052 in 2040, and 9,828 in 2060 (Table 2.2-8 and Figure 2.2-3). The increased dairy production is projected to result in an increase in dairy worker and associated population in the eight county area of 2,405 in 2010, 1,029 in 2020, 2,482 in 2040, and 4,255 in 2060 Table 2.2-8 and Figure 2.2-3).

Table 2.2-8
Comparison of Projected Number of Dairy Workers and Associated Population of 2006 Regional Water Plan with Projected Number of Dairy Workers and Associated Population for Increased Dairy Production (2008 Revisions) for Bailey, Castro, Deaf Smith, Hale, Lamb, Parmer, Lubbock and Terry Counties

No.*	County	2000 (number)	2006 Regional Water Plan Projected Dairy Workers and Associated Population: 2010 (number)	2020 (number)	2030 (number)	2040 (number)	2050 (number)	2060 (number)
1	Bailey	112	528	945	945	945	945	945
3	Castro	70	536	1,003	1,003	1,003	1,003	1,003
7	Deaf Smith	17	544	1,070	1,070	1,070	1,070	1,070
12	Hale	14	188	362	362	362	362	362
14	Lamb	294	746	1,198	1,198	1,198	1,198	1,198
18	Parmer	14	465	916	916	916	916	916
15	Lubbock	0	0	0	0	0	0	0
20	Terry	0	39	77	77	77	77	77
	Total	521	3,046	5,570	5,570	5,570	5,570	5,570

No.*	County	2008 Revised Projected Population of Dairy Workers Associated Population: 2010 (number)	2020 (number)	2030 (number)	2040 (number)	2050 (number)	2060 (number)
1	Bailey	865	1,124	1,242	1,372	1,515	1,674
3	Castro	961	1,250	1,380	1,525	1,684	1,860
7	Deaf Smith	1,015	1,190	1,314	1,452	1,604	1,772
12	Hale	557	625	690	762	842	930
14	Lamb	840	910	1,005	1,110	1,227	1,355
18	Parmer	1,085	1,330	1,469	1,623	1,793	1,980
15	Lubbock	56	73	81	89	99	109
20	Terry	74	97	108	119	131	145
	Total	5,451	6,599	7,289	8,052	8,895	9,825

No.*	County	Increased Projected Dairy Worker and Associated Population above 2006 Regional Water Plan: 2010 (number)	2020 (number)	2030 (number)	2040 (number)	2050 (number)	2060 (number)
1	Bailey	336	180	297	427	571	729
3	Castro	424	247	377	522	681	858
7	Deaf Smith	471	120	245	382	534	702
12	Hale	368	263	328	400	480	568
14	Lamb	94	-288	-192	-87	29	157
18	Parmer	620	414	553	706	876	1,064
15	Lubbock	56	73	81	89	99	109
20	Terry	35	20	31	42	54	68
	Total	2,405	1,029	1,719	2,482	3,324	4,255

* County number as listed in 2006 Regional Water Plan. <><><>

Projections of municipal water demand for the population of dairy workers and the associated population was based upon projected per capita municipal water demands of the 2006 regional Water Plan of each county, as shown in Table 2.2-9. Municipal water demand for dairy workers and the associated population for the eight county area was projected at 1,082 acre-feet per year in 2010, with municipal water demand for the eight county area projected at 1,277 acre-feet per year in 2020, 1,497 acre-feet per year in 2040, and 1,814 acre-feet per year in 2060 (Table 2.2-10 and Figure 2.2-4).

Table 2.2-9.
Projected Per Capita Municipal Water Demand for Projected Population of Dairy Workers and Associated Population of Study Counties

No.*	County	Projected Per Capita Municipal Water Use, with Water Conservation (2006 Regional Water Plan)						
		2008 (gpcd)	2010 (gpcd)	2020 (gpcd)	2030 (gpcd)	2040 (gpcd)	2050 (gpcd)	2060 (gpcd)
1	Bailey	174	173	170	167	164	163	163
3	Castro	175	174	171	168	165	164	164
7	Deaf Smith	192	190	182	176	172	170	170
12	Hale	153	151	148	145	142	141	141
14	Lamb	202	199	196	193	190	189	189
18	Parmer	165	164	160	157	154	153	153
15	Lubbock	207	205	202	199	196	195	195
20	Terry	209	208	205	202	199	198	198
	Total	188	186	182	179	177	176	176

* County number as listed in 2006 Regional Water Plan.

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Table 2.2-10. Comparisons of 2008 Revised Projections of Municipal Water Demand of Dairy Worker Associated Populations to 2006 Regional Water Plan Projections of Municipal Water Demand of Dairy Worker Associated Populations of Study Counties

No.*	County		2006 Regional Water Plan Projected Municipal Water Demand of Dairy Workers and Associated Population 2000 (acft)	2010 (acft)	2020 (acft)	2030 (acft)	2040 (acft)	2050 (acft)	2060 (acft)
1	Bailey		22	102	180	177	174	173	173
3	Castro		14	104	192	188	185	184	184
7	Deaf Smith		4	116	218	211	206	204	203
12	Hale		2	32	60	59	58	57	57
14	Lamb		67	167	263	259	255	254	254
18	Parmer		3	85	165	161	158	157	157
15	Lubbock		0	0	0	0	0	0	0
20	Terry		0	9	18	17	17	17	17
	Total		111	616	1,095	1,073	1,053	1,045	1,045

No.*	County		2000 (acft)	2008 Revised Projected Municipal Water Demand of Dairy Workers and Associated Population 2010 (acft)	2020 (acft)	2030 (acft)	2040 (acft)	2050 (acft)	2060 (acft)
1	Bailey		22	168	214	232	252	277	306
3	Castro		14	187	239	259	281	309	341
7	Deaf Smith		4	216	243	260	279	305	337
12	Hale		2	94	104	112	121	133	147
14	Lamb		67	188	200	218	237	260	287
18	Parmer		3	199	239	259	280	308	340
15	Lubbock		0	13	17	18	20	22	24
20	Terry		0	17	22	24	26	29	32
	Total		111	1,082	1,277	1,382	1,497	1,642	1,814

No.*	County			Increased Projected Municipal Water Demand of Dairy Workers and Associated Population over 2006 Regional Water Plan 2010 (acft)	2020 (acft)	2030 (acft)	2040 (acft)	2050 (acft)	2060 (acft)
1	Bailey			65	34	56	78	104	133
3	Castro			83	47	71	96	125	157
7	Deaf Smith			101	25	48	74	102	134
12	Hale			62	44	53	64	76	90
14	Lamb			21	-63	-42	-19	6	33
18	Parmer			114	74	97	122	150	183
15	Lubbock			13	17	18	20	22	24
20	Terry			8	5	7	9	12	15
	Total			466	182	309	444	597	769

* County number as listed in 2006 Regional Water Plan.

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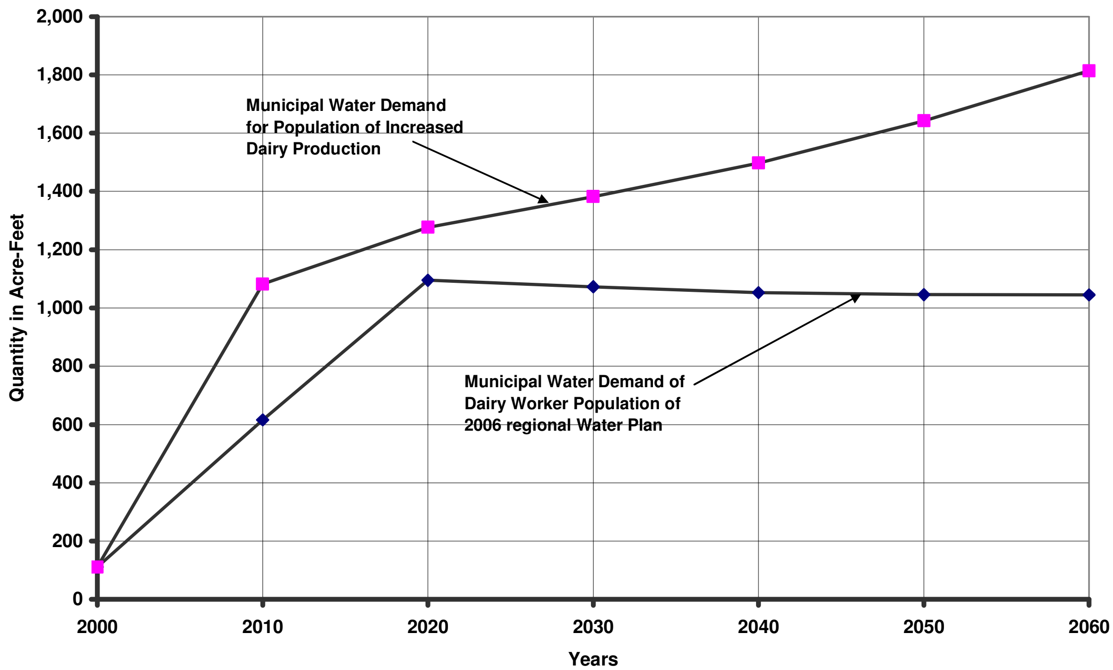
Figure 2.2-4: Projected Municipal Water Demand of Dairy Worker Population



The increased dairy production over the levels of the 2006 Regional Water Plan results in an increase of municipal water demand in the eight-county area of 466 acre-feet per year in 2010, 182 acre-feet per year in 2020, 444 acre-feet per year in 2040, and 769 acre-feet per year in 2060 (Table 2.2-10 and Figure 2.2-4).

2.2.3 Projections of Increased Irrigation Water Demand to Produce Feed Crops for Dairies Above Traditional Cropping Patterns

Crop production to provide feed for dairies results in some changes from traditional irrigation production, particularly to grow silage for nearby dairies, in comparison to producing grain or cotton for more distant markets. The increased irrigation water requirements for feed production for the revised dairy projections, in comparison to irrigation requirements for traditional cropping patterns are 16,938 acre-feet per year in 2010, 20,504 acre-feet per year in 2020, 25,019 acre-feet per year in 2040, and 30,528 acre-feet per year in 2060 (Table 2.2-11).[6] The projected increases are shown in Table

[6] The Texas Association of Dairymen, in cooperation with Dr. Ellen Jordan, professor and Extension dairy specialist, Texas A&M Center, Dallas, Texas.

2.2-11 for each of the 12 counties, and are distributed in the same proportions as the increased numbers of dairy cattle are distributed among the counties (See Table 2.2-3), with about 17 percent in Bailey County, 18 percent in each of Castro and Deaf Smith Counties, 9 percent in Hale County, 14 per cent in Lamb county, 20 percent in Parmer County, 1 percent in Lubbock County and about 1.5 percent in Terry County.

Table 2.2-11.
Projected Increased Irrigation Water Demand for Increased Dairy Production Above Irrigation Water Demand Projections of 2006 Regional Water Plan

No.*	County			Projected Increased Irrigation Water Demands to Produce Feed Crops for Dairies Above Traditional Cropping Patterns					
				2010 (acft)	2020 (acft)	2030 (acft)	2040 (acft)	2050 (acft)	2060 (acft)
1	Bailey			2,686	3,493	3,858	4,262	4,708	5,201
3	Castro			2,985	3,882	4,289	4,737	5,233	5,780
7	Deaf Smith			3,154	3,698	4,084	4,512	4,984	5,505
12	Hale			1,729	1,941	2,144	2,369	2,616	2,890
14	Lamb			2,610	2,828	3,123	3,450	3,811	4,210
18	Parmer			3,371	4,133	4,565	5,042	5,570	6,153
15	Lubbock			174	227	251	277	306	338
20	Terry			228	303	335	370	408	451
	Total			16,938	20,504	22,649	25,019	27,637	30,528

* County number as listed in 2006 Regional Water Plan. <><><><>

2.2.4 Projections of Total Increased Water Demand for Ethanol and Dairy Sectors of Llano Estacado Water Planning Region (Region O)

In Sections 2.2.1, 2.2.2, and 2.2.3 above, projections have been made of water demands for ethanol and dairy production activity levels that were not included in the 2006 Llano Estacado Regional Water Plan. These projections are summarized in Table 2.2-12, together with the total of ethanol, dairy, dairy worker population, and dairy feed production increased water demand projections for the Llano Estacado Water Planning Region, with projected water demand expressed in quantities greater than was included in the 2006 Regional Water Plan (Table 2.2-12). For ethanol, the quantity is 3,920 acre-feet per year, beginning in 2010 and continuing through 2060. For dairy cattle and milking parlor sanitation the quantity is 2,038 acre-feet per year greater in 2010 than was included in the 2006 regional Water Plan, 1,449 acre-feet per year less in 2020, 783

Table 2.2-12.
Projected Water Demand for Ethanol and Increased Dairy Production Above Water Demand Projections of 2006 Regional Water Plan

No.*	County	Projected Increased Water Demands Llano Estacado Water Planning Region (Region O) 2010 (acft)	2020 (acft)	2030 (acft)	2040 (acft)	2050 (acft)	2060 (acft)
	Ethanol Plants						
7	Deaf Smith	2,240	2,240	2,240	2,240	2,240	2,240
12	Hale	560	560	560	560	560	560
13	Hockley	1,120	1,120	1,120	1,120	1,120	1,120
	Total	3,920	3,920	3,920	3,920	3,920	3,920
	Dairies						
1	Bailey	229	-238	-58	142	363	606
3	Castro	360	-167	34	256	501	772
7	Deaf Smith	429	-397	-206	6	239	497
12	Hale	464	206	307	418	540	676
14	Lamb	-261	-1,093	-947	-786	-607	-410
18	Parmer	699	137	351	587	847	1,136
15	Lubbock	86	112	124	137	151	167
20	Terry	33	-9	6	24	43	64
	Total	2,038	-1,449	-388	783	2,077	3,507
	Dairy Worker Population						
1	Bailey	65	34	56	78	104	133
3	Castro	83	47	71	96	125	157
7	Deaf Smith	101	25	48	74	102	134
12	Hale	62	44	53	64	76	90
14	Lamb	21	-63	-42	-19	6	33
18	Parmer	114	74	97	122	150	183
15	Lubbock	13	17	18	20	22	24
20	Terry	8	5	7	9	12	15
	Total	466	182	309	444	597	769
	Dairy Feed Production						
1	Bailey	2,686	3,493	3,858	4,262	4,708	5,201
3	Castro	2,985	3,882	4,289	4,737	5,233	5,780
7	Deaf Smith	3,154	3,698	4,084	4,512	4,984	5,505
12	Hale	1,729	1,941	2,144	2,369	2,616	2,890
14	Lamb	2,610	2,828	3,123	3,450	3,811	4,210
18	Parmer	3,371	4,133	4,565	5,042	5,570	6,153
15	Lubbock	174	227	251	277	306	338
20	Terry	228	303	335	370	408	451
	Total	16,938	20,504	22,649	25,019	27,637	30,528
	Continued Next Page						

* County number as listed in 2006 Regional Water Plan.

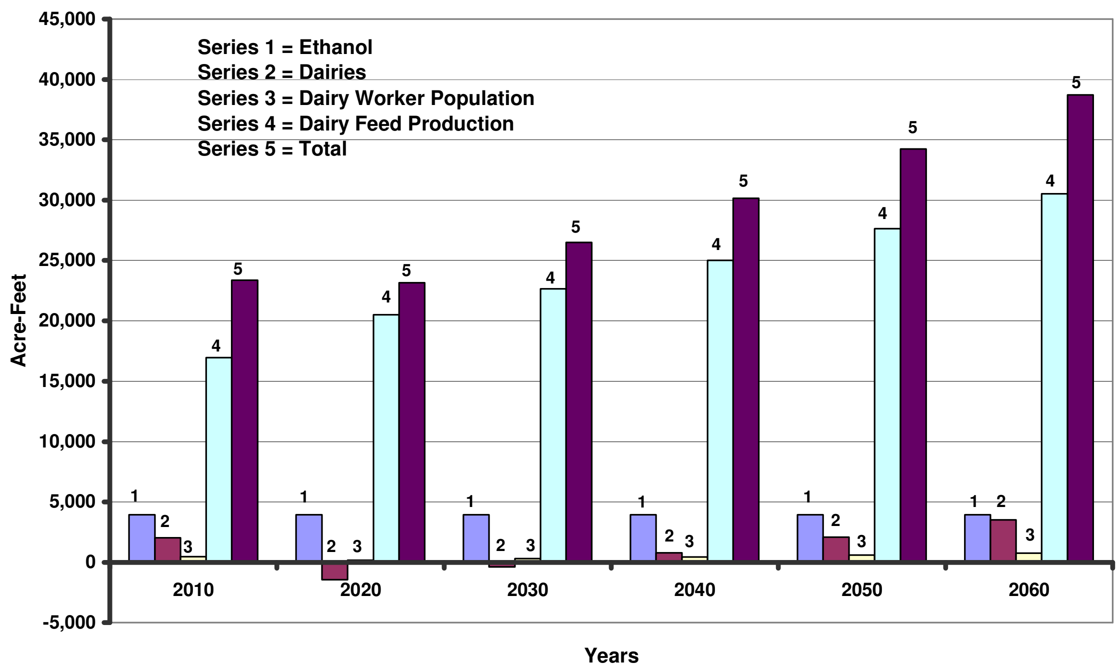
acre-feet greater in 2040, and is 3,507 acre-feet greater in 2060 (Table 2.2-12 and Figure 2.2-5). For dairy worker population, the projected increase in quantity of municipal

Table 2.2-12: Continued

No.*	County	2010 (acft)	2020 (acft)	2030 (acft)	2040 (acft)	2050 (acft)	2060 (acft)
		Projected Increased Water Demands Llano Estacado Water Planning Region (Region O)					
	Total Increased Water Demand						
1	Bailey	2,980	3,289	3,856	4,483	5,175	5,940
3	Castro	3,428	3,763	4,394	5,090	5,859	6,709
7	Deaf Smith	5,923	5,565	6,167	6,831	7,565	8,375
12	Hale	2,815	2,751	3,064	3,410	3,792	4,215
13	Hockley	1,120	1,120	1,120	1,120	1,120	1,120
14	Lamb	2,370	1,671	2,134	2,646	3,210	3,833
18	Parmer	4,184	4,343	5,013	5,751	6,568	7,471
15	Lubbock	273	356	393	434	479	529
20	Terry	270	298	348	402	463	530
	Total	23,362	23,157	26,490	30,166	34,231	38,723
	Percent of Total Increase						
	Ethanol	16.78%	16.93%	14.80%	12.99%	11.45%	10.12%
	Dairies	8.73%	-6.26%	-1.47%	2.60%	6.07%	9.06%
	Dairy Worker Population	2.00%	0.79%	1.17%	1.47%	1.74%	1.98%
	Dairy Feed Production	72.50%	88.54%	85.50%	82.94%	80.74%	78.84%
	Total	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

* County number as listed in 2006 Regional Water Plan. <><><><>

Figure 2.2-5: Projected Increased Water Demand -- Region O



water demand is 466 acre-feet per year in 2010, 444 acre-feet in 2040, and 769 acre-feet per year in 2060 (Table 2.2-12 and Figure 2.2-5). For dairy feed production, the projected increased irrigation water demand is 16,938 acre-feet per year in 2010, 25,019 acre-feet per year in 2040, and 30,528 acre-feet per year in 2060 (Table 2.2-12 and Figure 2.2-5). The total increased water demand for ethanol production, dairies, dairy population and dairy feed production is 23,362 acre-feet per year in 2010, of which 16.7 percent is for ethanol production, 8.7 percent is for dairies, 2.0 percent is for dairy worker population, and 72.5 percent is for dairy feed production (Table 2.2-12 and Figure 2.2-5). The total is 30,166 acre-feet per year in 2040, and 38,723 acre-feet per year in 2060, of which ethanol production is 10.1 percent, dairies are 9.1 percent, dairy worker population is 1.98 percent, and dairy feed production is 78.8 percent (Table 2.2-12 and Figure 2.2-5).

Section 3
Evaluation of Water Supplies from the Dockum Aquifer of Bailey, Castro, Deaf Smith, Hale, Lamb, and Parmer Counties

Executive Summary

A potential supply of additional water in Bailey, Castro, Deaf Smith, Hale, and Parmer Counties is in the Dockum Aquifer which lies underneath the Ogallala Aquifer. The Dockum Aquifer has experienced little development except in areas where it is relatively shallow. Recharge to the Dockum in the study area consists of precipitation and streamflow losses in areas where the sediments are exposed at the land surface toward the northwest in New Mexico and Texas and downward leakage from the overlying Ogallala. The potential for a significant amount of recharge is extremely limited.

The best water bearing zone of the Dockum is sandstone in the lower part of the aquifer. Dockum wells in the vicinity of Hereford and in northeast Castro County typically are 800-950 ft deep, with deepest wells of about 1,400 ft in Lamb County. Typical yields of Dockum wells are estimated to range from about 400 gpm in the Deaf Smith County to about 200 gpm in the southern part of the study area. The salinity of water in the Deaf Smith County area ranges from concentrations of 800 to 1,500 milligrams per liter of total dissolved solids, with salinity in the southern part of the study area greater than 20,000 mg/L of total dissolved solids.

It is estimated that there are nearly 85 million acre-feet of groundwater in the Dockum in this six county area, with the greatest amount of groundwater in storage in Deaf Smith County having salinity of 5,000 mg/L or less. Bailey and Lamb Counties have a considerable volume of Dockum groundwater, but the salinity is estimated to be mostly greater than 20,000 mg/L. Potential well field designs were prepared for two well fields (Deaf Smith and Parmer-Castro-Lamb County) and at three pumping rates 0.2, 1, 3, and 10 million gallons per day (MGD). The most economical water supply, not considering water treatment, was from the Deaf Smith well field pumping at a rate of 3 MGD. The delivery of raw water to a terminal near the well field is estimated to cost about $305 per acre foot.

Costs were estimated for desalination using Reverse Osmosis (RO) and concentrate disposal using solar evaporation and deep well injection for 0.2, 1, 3, and 10 MGD sized Dockum Aquifer well fields having 1,500, 3,000, 5,000, and 20,000 mg/L concentrations of TDS. Estimated total costs for raw water, desalination, and concentrate disposal for water from the Dockum Aquifer with TDS of 1,500 mg/L range from $5.35 per 1,000 gallons for a 0.2 MGD facility, to $3.76 per 1,000 gallons for a 1 MGD facility, to $2.75 per 1,000 gallons for a 3 MGD facility, and $2.29 per 1,000 gallons for a 10 MGD facility. Estimated total costs for raw water, desalination, and concentrate disposal for water from the Dockum Aquifer with TDS of 3,000 mg/L range from $6.65 per 1,000 gallons for a 0.2 MGD facility, to $4.77 per 1,000 gallons for a 1 MGD facility, to $3.07 per 1,000 gallons for a 3 MGD facility, and $2.61 per 1,000 gallons for a 10 MGD facility. Estimated total costs for raw water, desalination, and concentrate disposal for water from the Dockum Aquifer with TDS of 5,000 mg/L range from $7.94 per 1,000 gallons for a 0.2 MGD facility, to $5.57 per 1,000 gallons for a 1 MGD facility, to $4.08 per 1,000 gallons for a 3 MGD facility, and $3.23 per 1,000 gallons for a 10 MGD facility. Estimated total costs for raw water, desalination, and concentrate disposal for water from the Dockum Aquifer with TDS of 20,000 mg/L range from $11.44 per 1,000 gallons for a 0.2 MGD facility, to $7.21 per 1,000 gallons for a 1 MGD facility, to $5.62 per 1,000 gallons for a 3 MGD facility, and $5.10 per 1,000 gallons for a 10 MGD facility.

3.1 Groundwater Availability from the Dockum Aquifer

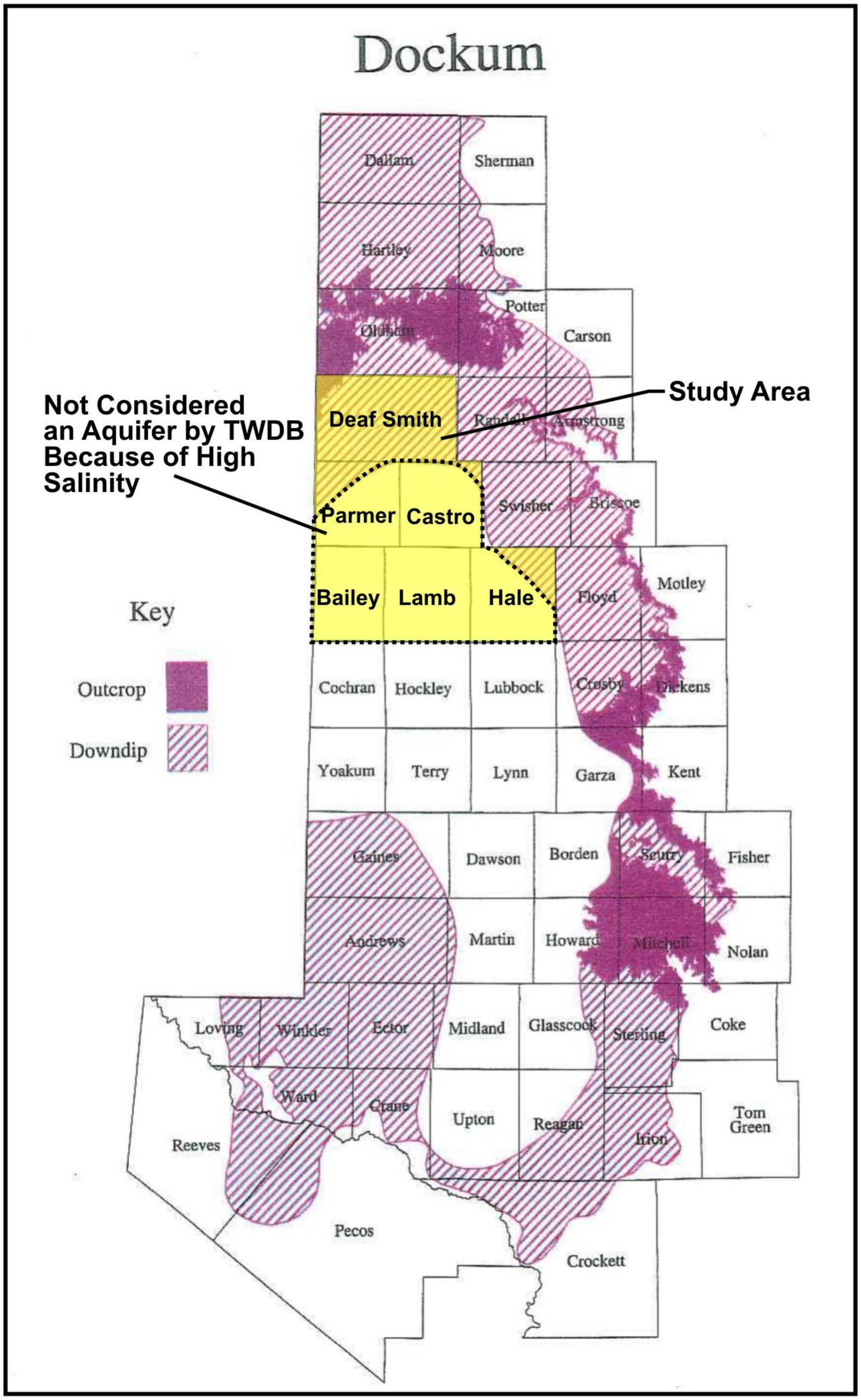
A potential supply of additional water in Bailey, Castro, Deaf Smith, Hale, Lamb, and Parmer Counties is in the Dockum Aquifer which is overlain by the Ogallala Aquifer (Figure 3.1-1). The Dockum Aquifer has experienced little development except in areas where it is relatively shallow and the water quality is suitable for the intended use. In the six counties of interest, only small to modest development has occurred in Deaf Smith County and the eastern part of Hale County. In many cases, wells appear to be screened in both the Ogallala and Dockum.

In this section, Dockum Aquifer data from previous studies and reports and well data from the TWDB database will be used to:

- Briefly characterize the Dockum Aquifer,
- Estimate the amount of groundwater in storage, by selected ranges of salinity, in each of the counties,
- Estimate the drawdown in two potential well fields pumping 0.2, 1, 3 and 10 million gallons per day (MGD) at the end of 10 years, and
- Prepare preliminary engineering designs of potential well fields with estimates of construction and operating costs.

3.1.1 Hydrogeologic Framework of Dockum

The geologic setting of the Dockum Aquifer (Dockum) is within the Upper Triassic Dockum Group, which occurs mostly in the Texas Panhandle and eastern New Mexico. Outcrops of the Dockum are primarily to the northwest in the Canadian River and the Pecos River Valleys in Texas and New Mexico. As shown in Figure 3.1-2, the outcrop of the Dockum is along the perimeter of the aquifer. A generalized cross-section is presented in Figure 3.1-3 and shows that the Dockum dips from an uplands area along the Pecos River in New Mexico to the Rolling Plains in north-central Texas. As shown in Figure 3.1-3, the Dockum is overlain by the Ogallala Aquifer of the Tertiary System and the Edwards-Trinity Aquifer (High Plains) of the Cretaceous System where they exist. Underneath the Dockum is the Permian System. The Dockum forms a



Copied from Ashworth and Hopkins, 1995.

Figure 3.1-1. Location of Study Area and Dockum in Texas

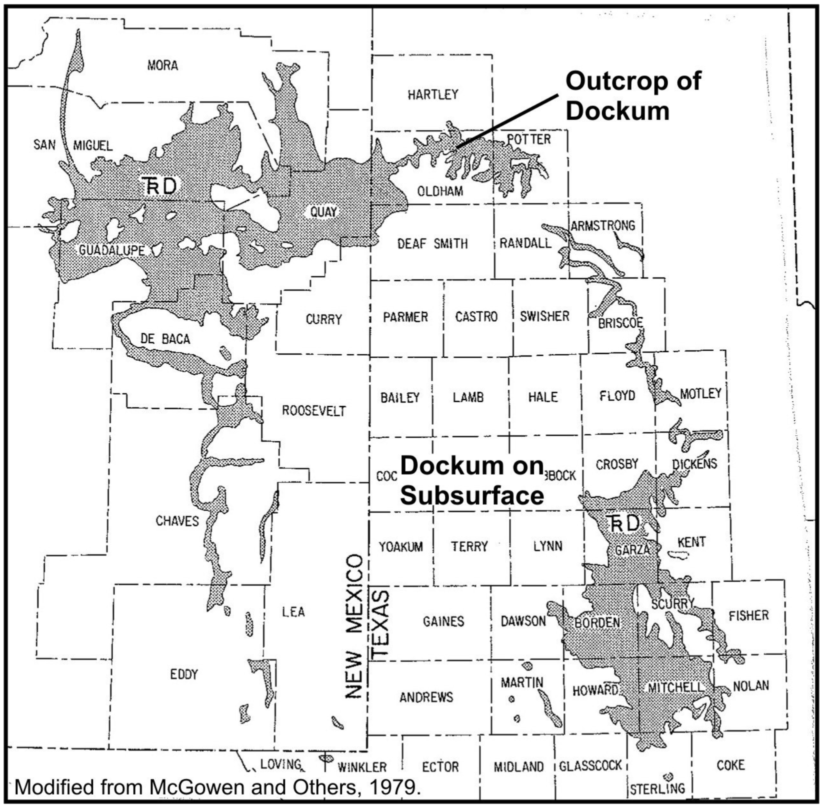


Figure 3.1-2. Location of Dockum

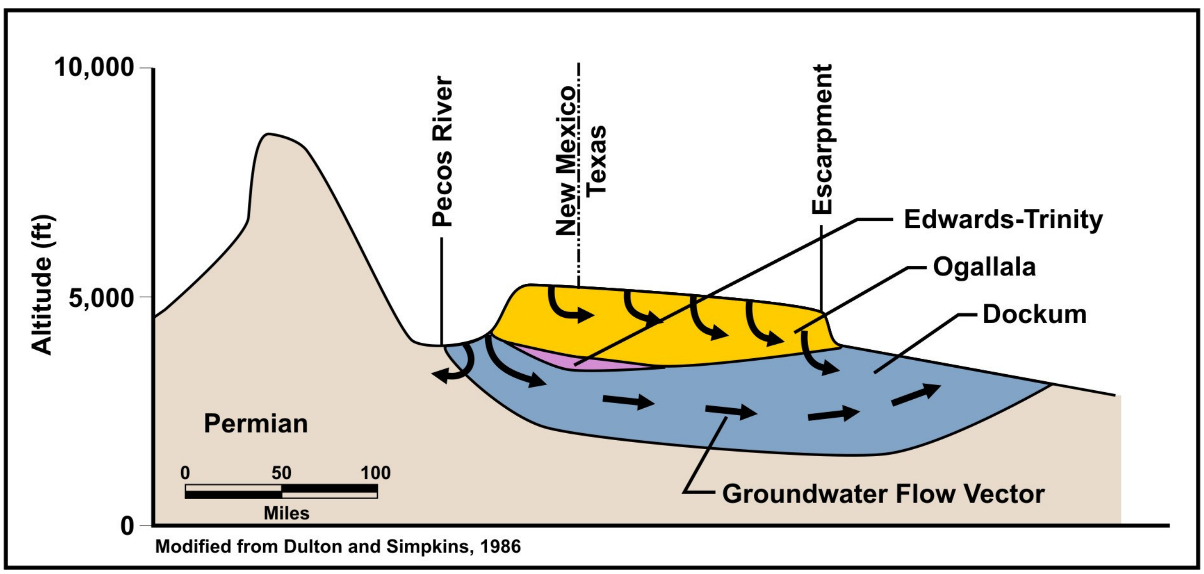


Figure 3.1-3. Regional Groundwater Flow Paths in Ogallala and Dockum

bowl-shaped basin with the lowest area having an elevation of 1,000 to 1,200 ft-msl,[1] which is about 2,000 ft below land surface. The topographically low part of the Dockum is called the Midland Basin. The highest elevation is in the northwest part of the aquifer and is slightly over 5,000 feet mean sea level (ft-msl). The Dockum is composed of four formations, including Cooper Canyon, Trujillo, Tecovas, and Santa Rosa, which are layers of sandstone, siltstone, mudstone, shales and conglomerate. A more detailed geologic and hydrogeologic summary of the Dockum Group is presented in the TWDB Draft Report, "Groundwater availability Model for the Dockum Aquifer."[2]

Regionally, the groundwater levels show a gradient toward the east and southeast. In the study area, the water levels range from about 4,200 ft-msl in western Deaf Smith County to 3,000 ft-msl in eastern Hale County.

Recharge to the Dockum in the study area consists of: (1) precipitation and streamflow losses in areas where the sediments are exposed at the land surface toward the northwest in New Mexico and Texas and (2) downward leakage from the overlying Ogallala and Edwards-Trinity. Little, if any recharge would occur by the upward movement of groundwater in the underlying Permian rocks. The potential for a significant amount of recharge from precipitation on the outcrop of the Dockum upgradient of the study area is extremely limited because of: (1) relatively small outcrop area, (2) low precipitation in this area, (3) little streamflow across the outcrop, (4) substantial distance between outcrop area and study area, and (5) low water conveyance (transmissive) properties of the Dockum. Recharge from the Ogallala and Edwards-Trinity (downward leakage) is restricted, but not prevented in the long-term, by relatively thick and poorly permeable shale, mudstone and siltstone.

Discharge from the Dockum includes: (1) underflow to the southeast, (2) wells, and (3) possibly upward leakage to the Ogallala and Edwards-Trinity.

Geologic and hydrogeologic delineations of the Dockum in the study area have been made by McGowan, Granata and Seni,[3] Dutton and Simpkins (1986),[4] and Bradley, R.G. and

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[1] McGowen, J.H., Granata, G.E., and Seni, S.J., 1977, Depositional Systems, Uranium Occurrence and Postulated Ground-water history

[2] Ewing, J.E. and others, June 2008, Draft Final Report Broundwater Availability Model for the Dockum Aquifer.

[3] McGowen, J.H., Granata, G.E., and Seni, S.J., 1979, Depositional framework of the Lower Dockum Group (Triassic)-Texas Panhandle: The University of Texas Bureau of Economic Geology Report of Investigations No. 97.

[4] Dutton, A.R. and Simpkins, W.W., 1986, Hydrogeochemistry and water resources of the Triassic Lower Dockum Group in the Texas Panhandle and Eastern New Mexico: The University of Texas Bureau of Economic Geology Report of Investigations No. 161.

Kalaswad, S (2003).[5] Their reports show that the Dockum outcrops in the extreme northwest corner of Deaf Smith County and to be overlain by the Ogallala elsewhere. Fallin (1989)[6] shows relatively thin sections of Cretaceous formations (Edwards-Trinity Aquifer) between the Ogallala and Dockum in southern half of Bailey County and the southwest part of Lamb County.

A map of the top of the Dockum is shown in Figure 3.1-4. The highest elevation is about 4,250 ft-msl in northwest Deaf Smith County; and, the lowest elevation is about 3,050 ft-msl in southeast Hale County. Across the study area, the top of the Dockum slopes to the east and southeast at about 10 ft per mile (ft/mi).

A map of the bottom of the Dockum is shown in Figure 3.1-5. The highest elevation is about 3,000 ft-msl in northwest Deaf Smith County; and, the lowest elevation is about 1,750 ft-msl in southern Bailey and Hale County. Across the study area, the base of the Dockum generally slopes toward the Midland basin, which is south of the study area, and at a rate of about 15 ft/mi.

McGowen and others (1977) have informally divided the Dockum into two layers, primarily on the basis of depositional history and lithology. For each of the layers, they, have drawn a regional thickness map.[7] Thicknesses of the Upper and Lower Dockum are shown in Figures 3.1-6 and 3.1-7, respectively. The thickness of the Upper Dockum varies from less than 200 ft along the northern and eastern edges of the study area to about 1,000 ft in Bailey County. The Lower Dockum's thickness is relatively uniform, varying between about 600 and 1,000 ft. The thickness of the Dockum tends to be greater in the southern part of the study area.

McGowen and others (1977) have also mapped the percent sandstone in the two layers.[8] The occurrence of sandstone is of considerable interest because it has the best water-bearing properties of any lithologic unit in the Dockum. Maps of the percent sandstone in the Upper and Lower Dockum are shown in Figures 3.1-8 and 3.1-9, respectively. The sandstones in the Upper Dockum are between 0 to 30 percent, with much of the area in 0-10 and 10-20 percent ranges. The Lower Dockum tends to have more sandstone, with ranges commonly in the 20-40 percent ranges. Bradley and Kalaswad (2003) studied numerous geophysical logs of the Dockum and

[5] Bradley, R.G. and Kalaswad, Sanjeev, (Dec 2003), The groundwater resources of the Dockum Aquifer in Texas: Texas Water Development Board Report 359.
[6] Fallin, J.A., March 1989, Hydrogeology of the Lower Cretaceous Strata under the Southern High Plains of Texas and New Mexico: Texas Water Development Board Report 314.
[7] Op. cit.
[8] Op. cit.

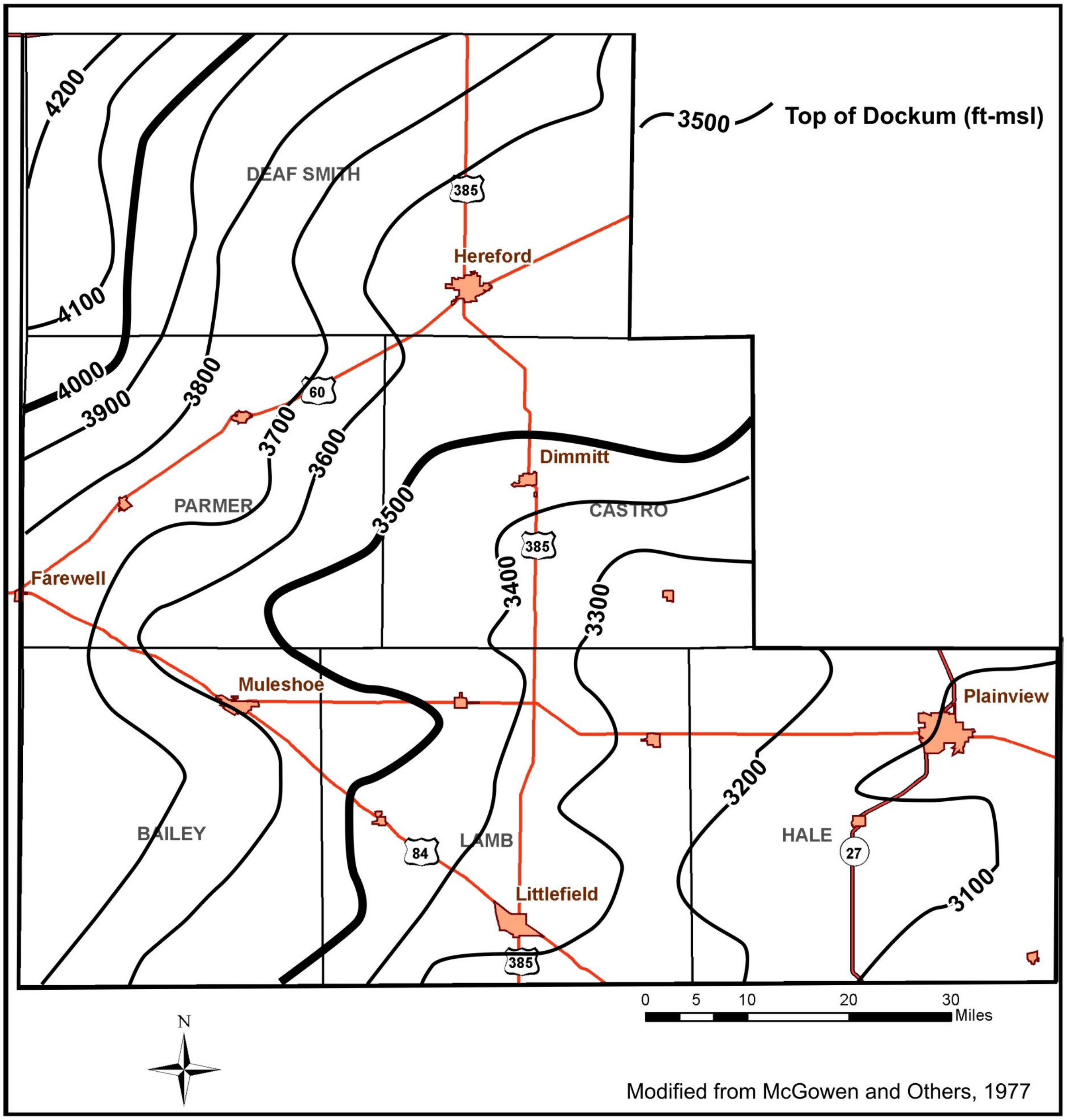


Figure 3.1-4. Top of the Dockum

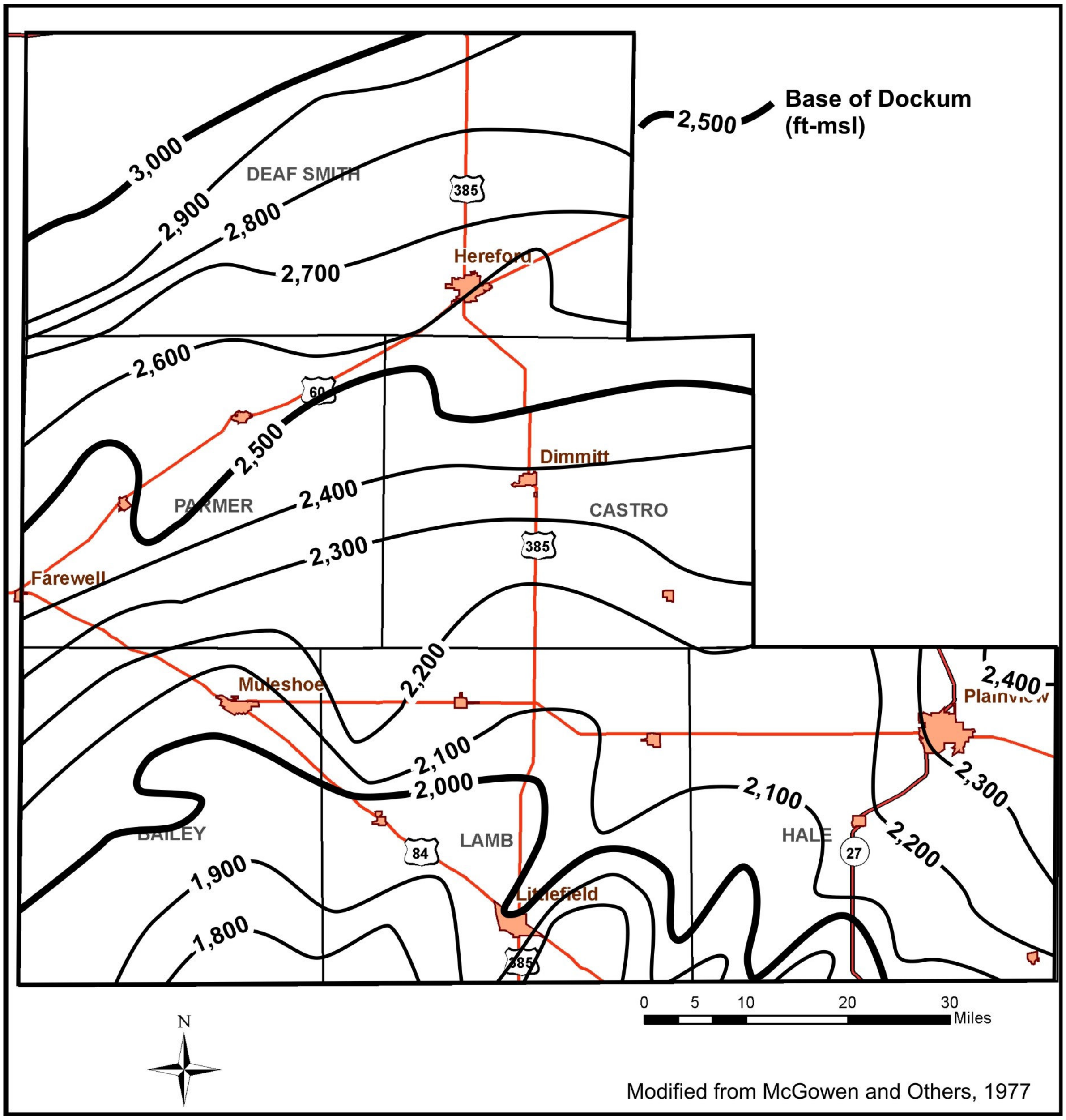


Figure 3.1-5. Base of the Dockum

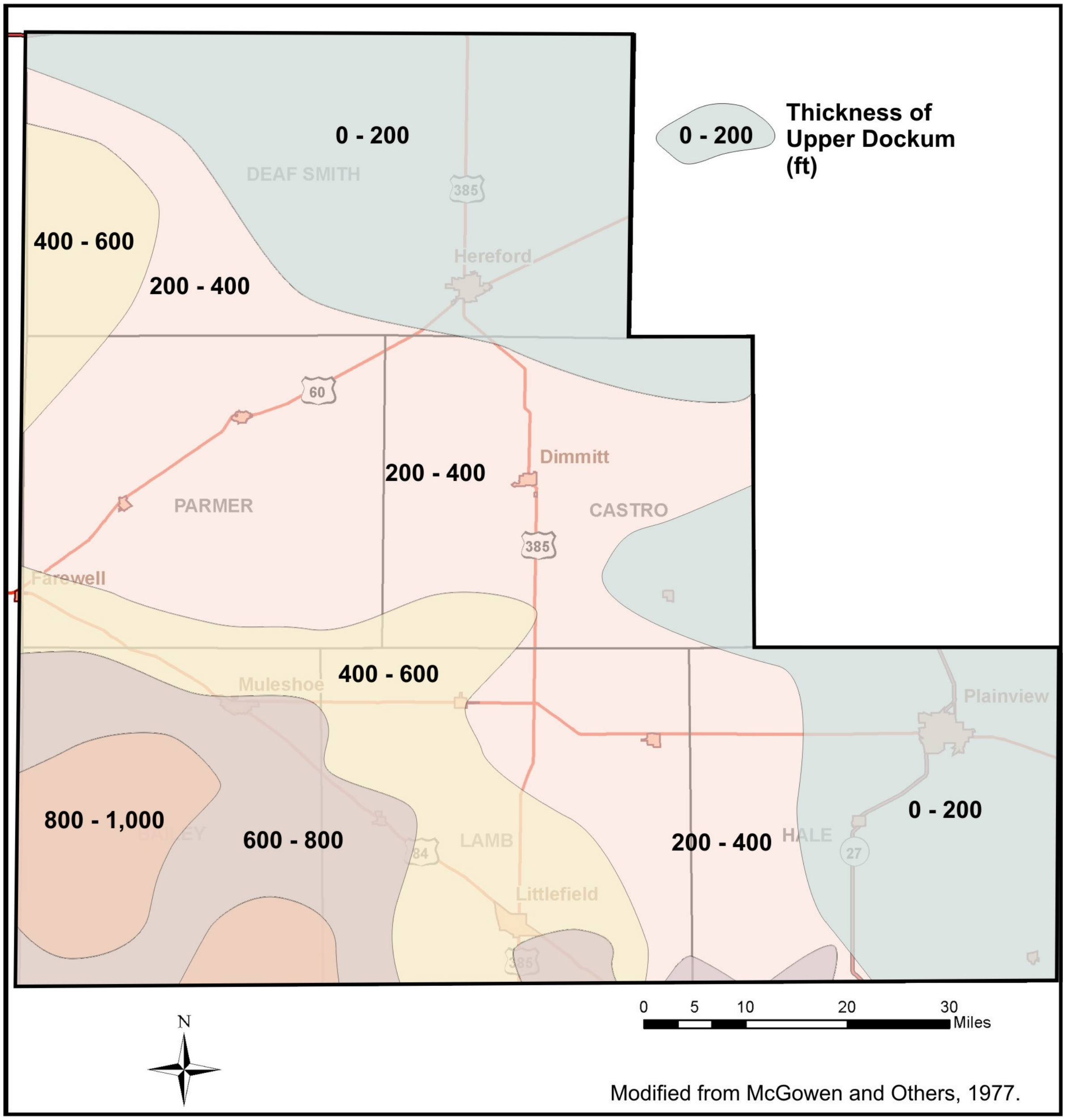


Figure 3.1-6. Thickness of the Upper Dockum

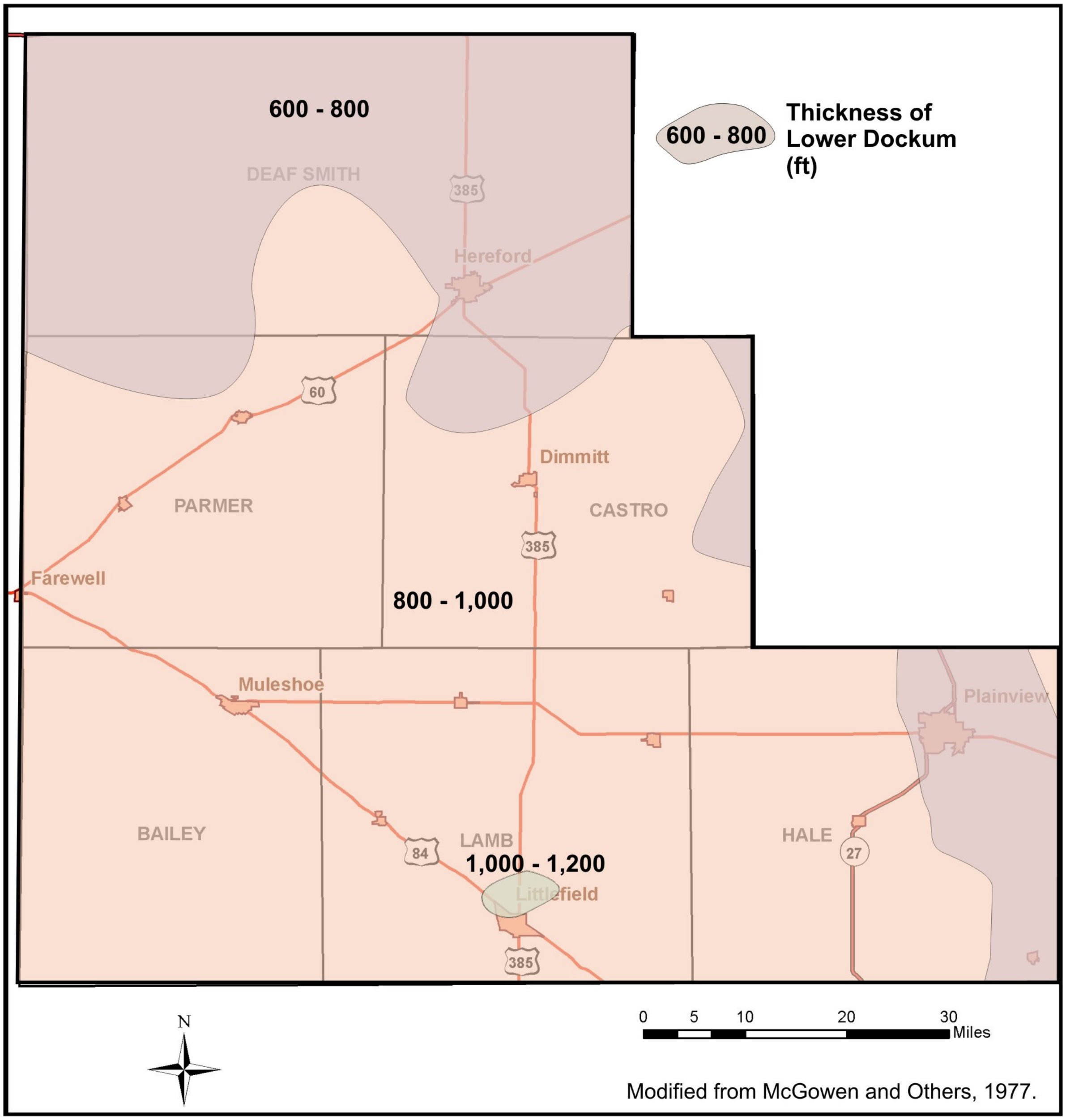


Figure 3.1-7. Thickness of the Lower Dockum

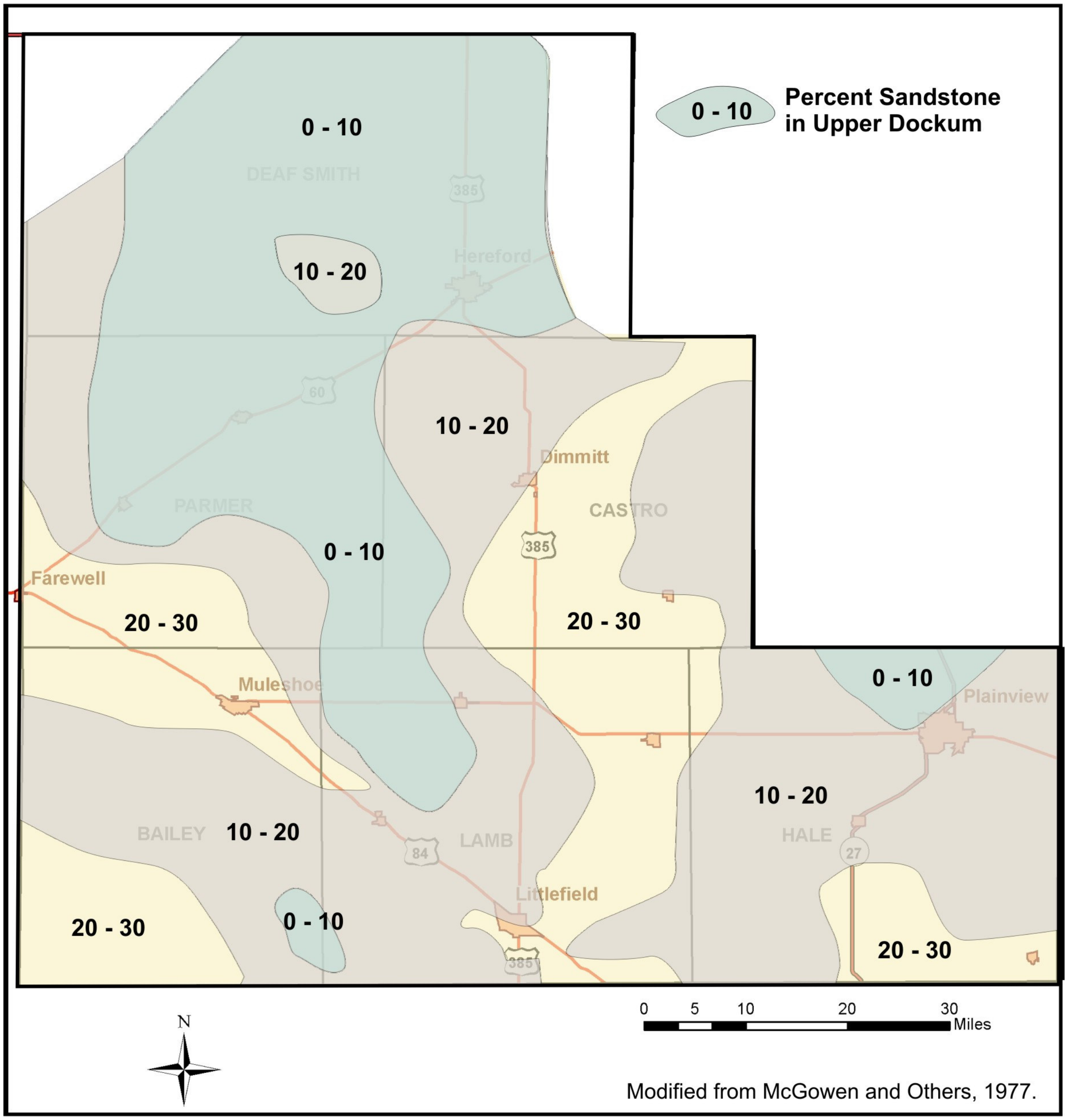


Figure 3.1-8. Percent Sandstone in Upper Dockum

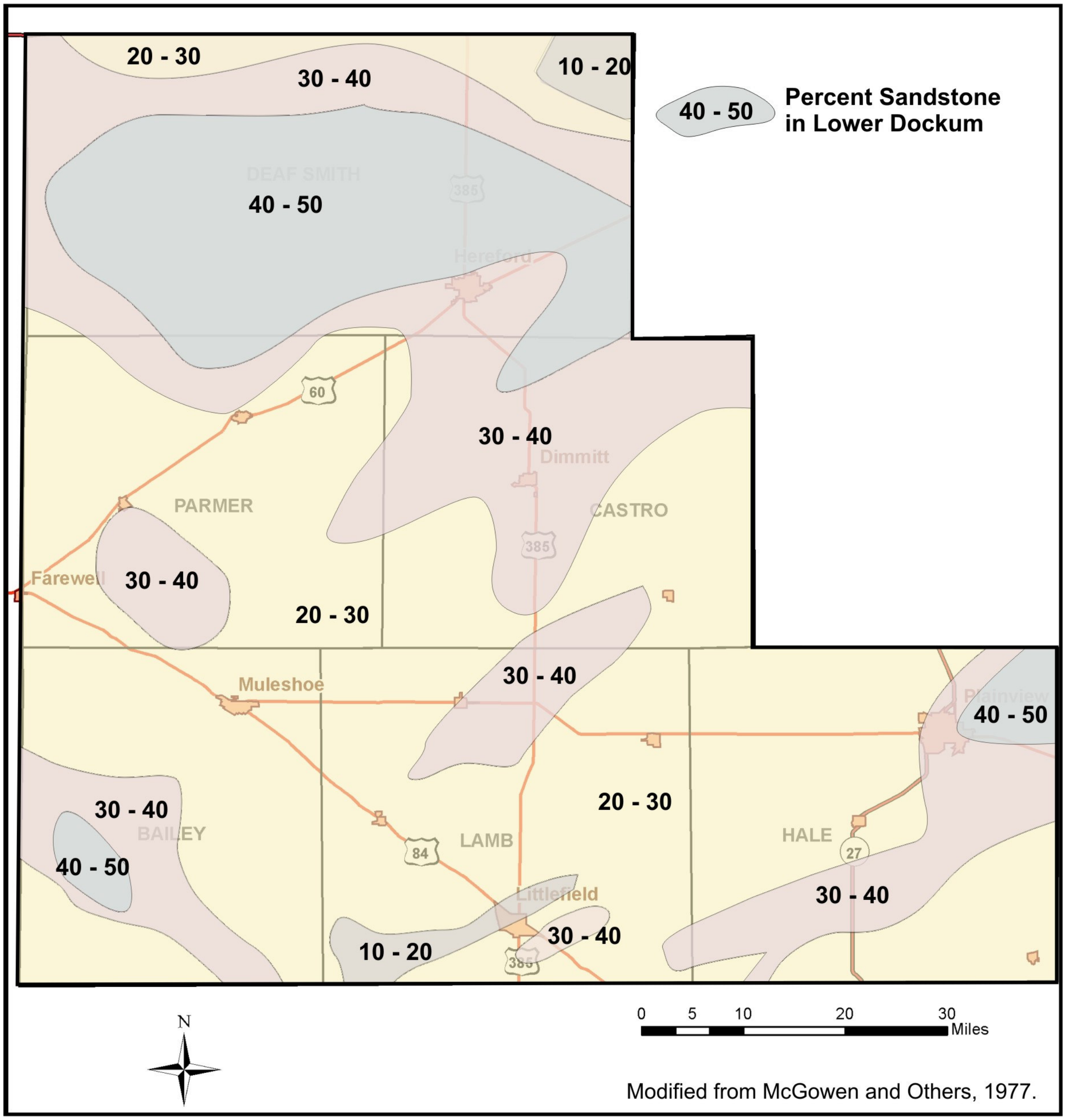


Figure 3.1-9. Percent Sandstone in Lower Dockum

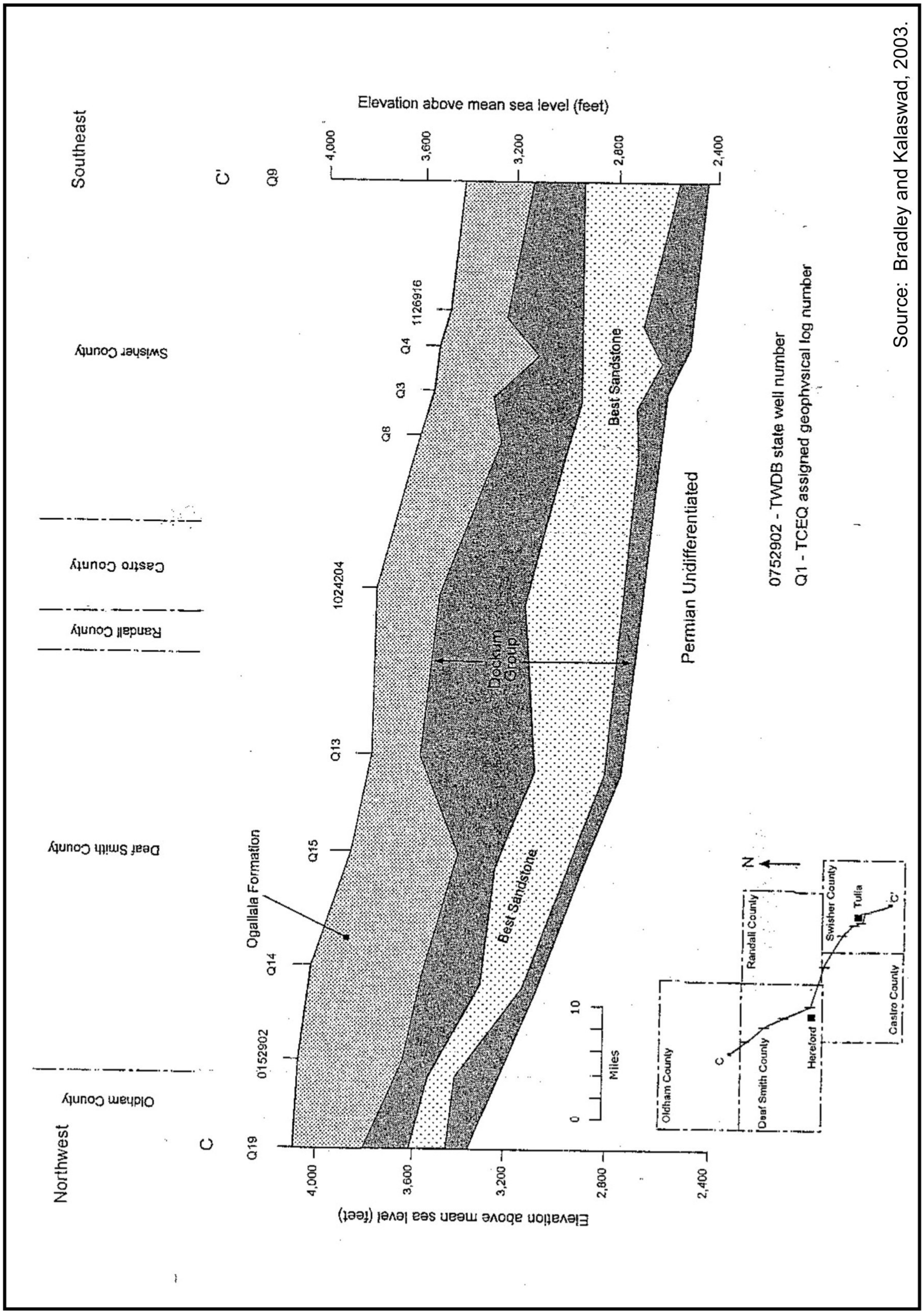


Figure 3.1-10. Northwest-Southeast Cross-Section of Dockum through Deaf Smith and Castro Counties

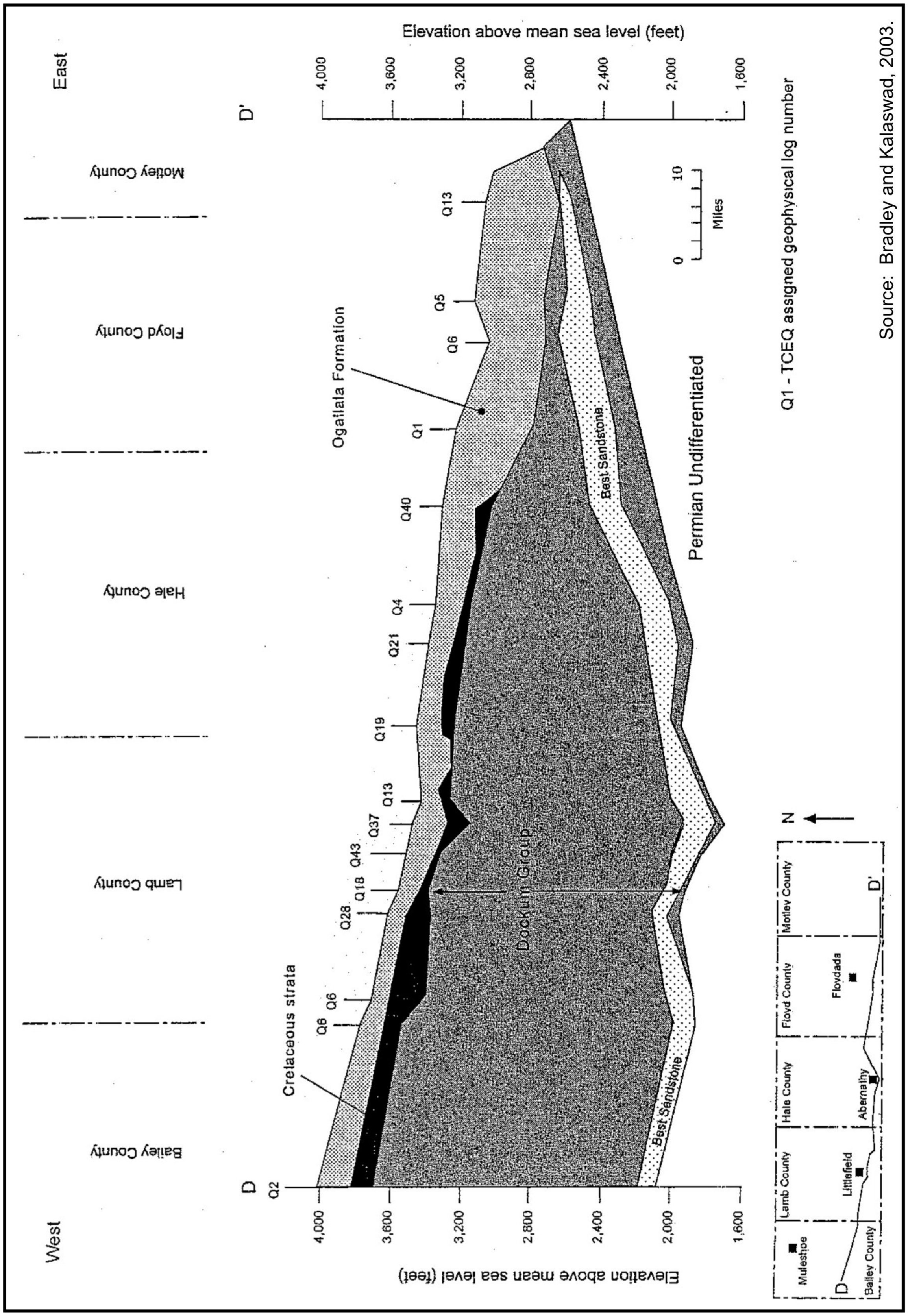


Figure 3.1-11. West-East Cross-Section of Dockum through Bailey, Lamb, and Hale Counties

prepared two cross-sections and delineated the "Best Sandstone" in the study area (Figures 3.1-10 and 3.1-11). The "Best Sandstone" is near the bottom of the Dockum. It is thickest in Castro County (about 400 ft) and thinnest in Bailey County (about 100 ft). In consideration of the thicknesses and percent sandstone, the Lower Dockum appears to have the potential to yield much more water to wells than the Upper Dockum.

Dutton and Simpkins (1986) also mapped the groundwater levels and salinity (concentration of total dissolved solids) in the Lower Dockum. Groundwater levels and water salinity are shown in Figures 3.1-12 and 3.1-13, respectively.[9] The groundwater levels have a consistent west to east trend, ranging from over 4,000 ft-msl in southwest Deaf Smith County to less than 3,000 ft-msl in southeast Hale County. The salinity map shows the water to be relatively fresh in the northern half of Deaf Smith County, but quickly trends to very saline (greater than 20,000 milligrams per liter of total dissolved solids (mg/L of TDS)) in the south-central part of the study area. This trend generally coincides with trends of the elevation of the base of the Dockum.

3.1.2 Location of Dockum Wells

The Texas Water Development Board (TWDB) maintains a water well database. The major sources of information are: TWDB and U.S. Geological Survey (USGS) groundwater studies in the county, TWDB monitoring programs, groundwater conservation districts, and well driller reports.

A general characterization of the Dockum using TWDB well data was attempted by downloading the database for each of the six counties. Then, the data were filtered to include only wells that were identified as being screened in the Dockum. The locations of the Dockum wells are shown in Figure 3.1-14. Most all the Dockum wells in the study area are east of Hereford, with a second concentration of wells is in the northeast corner of Castro County. Most of the other wells are rather evenly distributed in the northern half of Deaf Smith County. No Dockum wells are listed in Bailey, Lamb and Parmer Counties and only one is located in Hale County.

The location of Dockum wells is mostly related to: (1) relatively low groundwater availability from the Ogallala and (2) quality of water in the Dockum is suitable for intended uses without treatment.

[9] Op. cit.

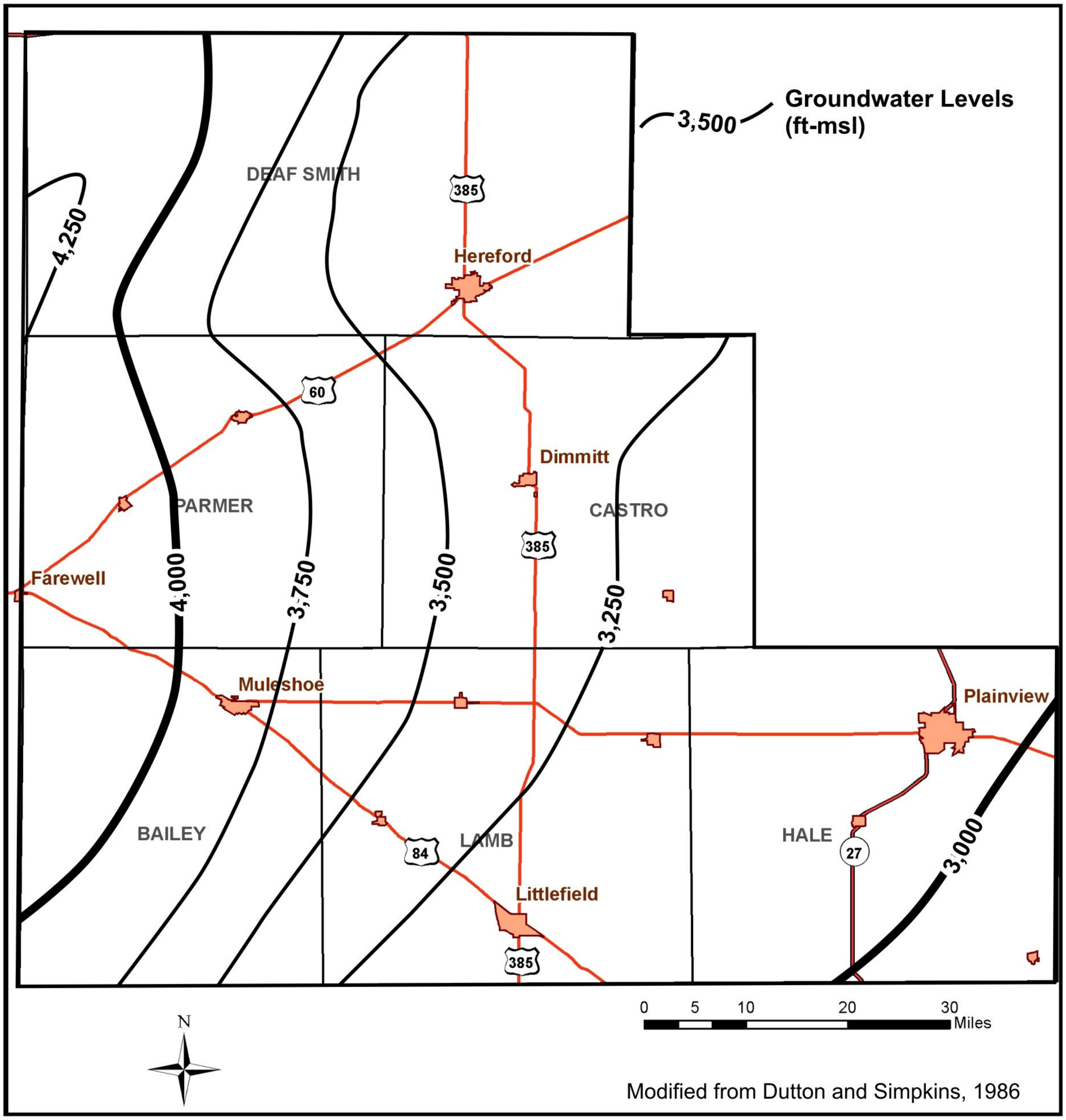


Figure 3.1-12. Approximate Groundwater Levels in Lower Dockum

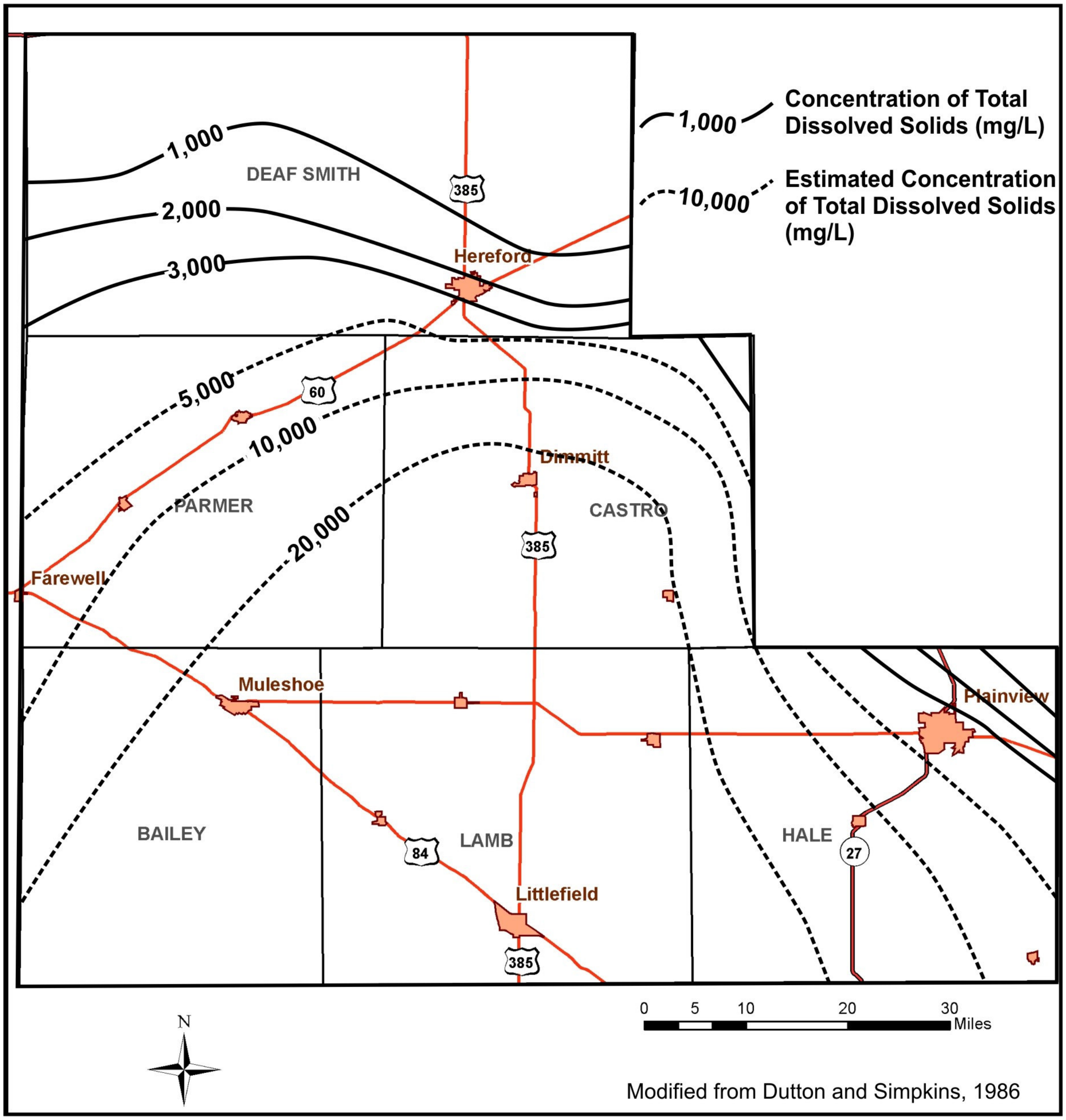


Figure 3.1-13. Approximate Salinity of Groundwater in the Lower Dockum

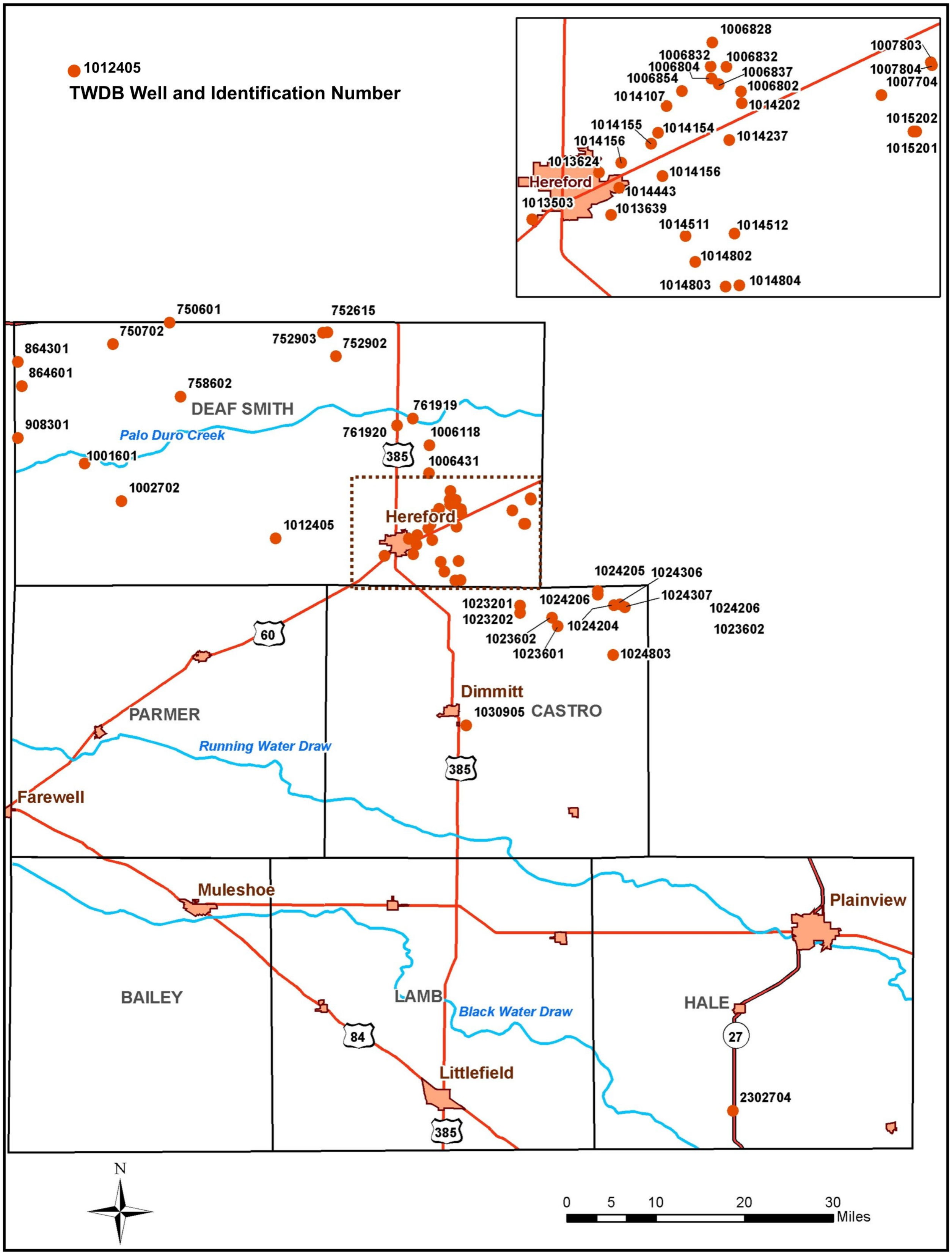


Figure 3.1-14. Location of Dockum Water Wells in TWDB Database

3.1.3 Wells Depths

The depth of Dockum water wells in the TWDB database are shown in Figure 3.1-15. In the vicinity of Hereford and in northeast Castro County, typical well depths are in the 800-950 ft. As one approaches the Dockum outcrop in northwest Deaf Smith County and eastern Hale County, the wells become relatively shallow (less than 400 ft deep).

3.1.4 Salinity of Water in Wells

The distribution of water quality data (Figure 3.1-16) with laboratory analyses from Dockum wells is very sparse except east of Hereford and in northwest Deaf Smith County. In this area, the data show that the salinity of groundwater in the Dockum is typically less than 1,000 mg/L of TDS. A very noticeably exception is a sample from a well near Dimmitt (well # 1030905) which has a salinity of over 25,000 mg/L TDS, nearly the salinity of seawater. This well is reported to be 1,088 ft deep. No salinity data for Dockum wells are available in Bailey, Lamb, Hale, and Parmer Counties.

3.1.5 Groundwater in Storage

For purposes of this analysis, two hydrologic conditions of groundwater are considered. One is the amount of groundwater that would be released by draining in the Dockum; and, the other is the amount that would be release by a removal of artesian pressure. The water storage characteristic of aquifers is such that much, much more water is released by draining an aquifer than by reducing the artesian pressure.

The approach used in calculating the amount of groundwater in the Dockum considers: (1) each of the seven ranges of salinity (less than 1,000, 1,000-2,000, 2,000-3,000, 3,000-5,000, 5,000-10,000, 10,000-20,000 and greater than 20,000 mg/L TDS) in Figure 3.1-13, (2) Upper and Lower Dockum, (3) drainable and artesian water, and (4) county. A general description of the steps in making the calculations follows. Where applicable, calculations are made by the Upper and Lower Dockum, seven salinity ranges and each county.

1. Estimate the area,
2. Estimate the thickness and the percent sandstone,
3. Estimate the top and bottom of the Upper and Lower Dockum and the potentiometric surface,
4. Multiply the thickness and percent sandstone to get the thickness of the sandstone,

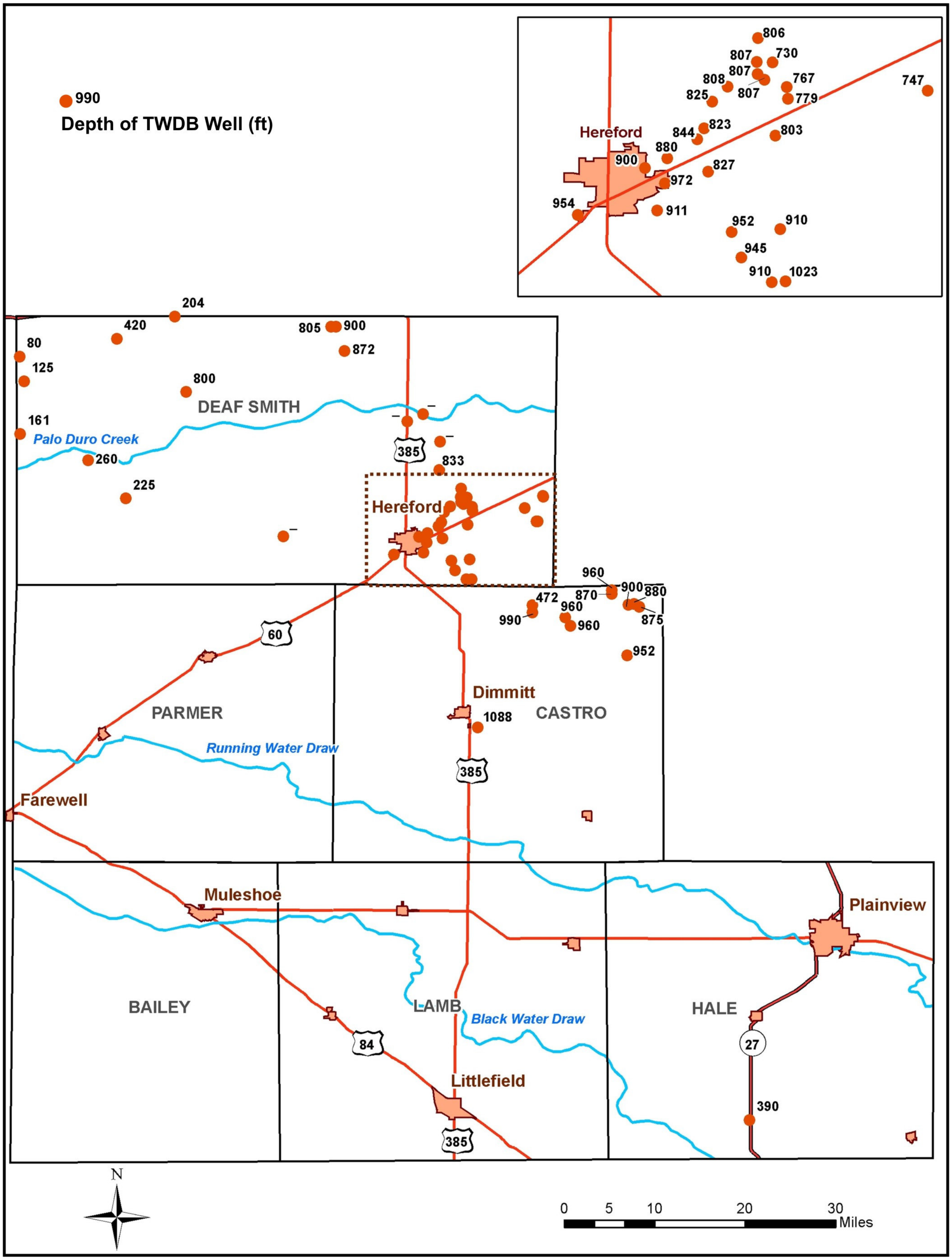


Figure 3.1-15. Depth of Dockum Water Wells in TWDB Database

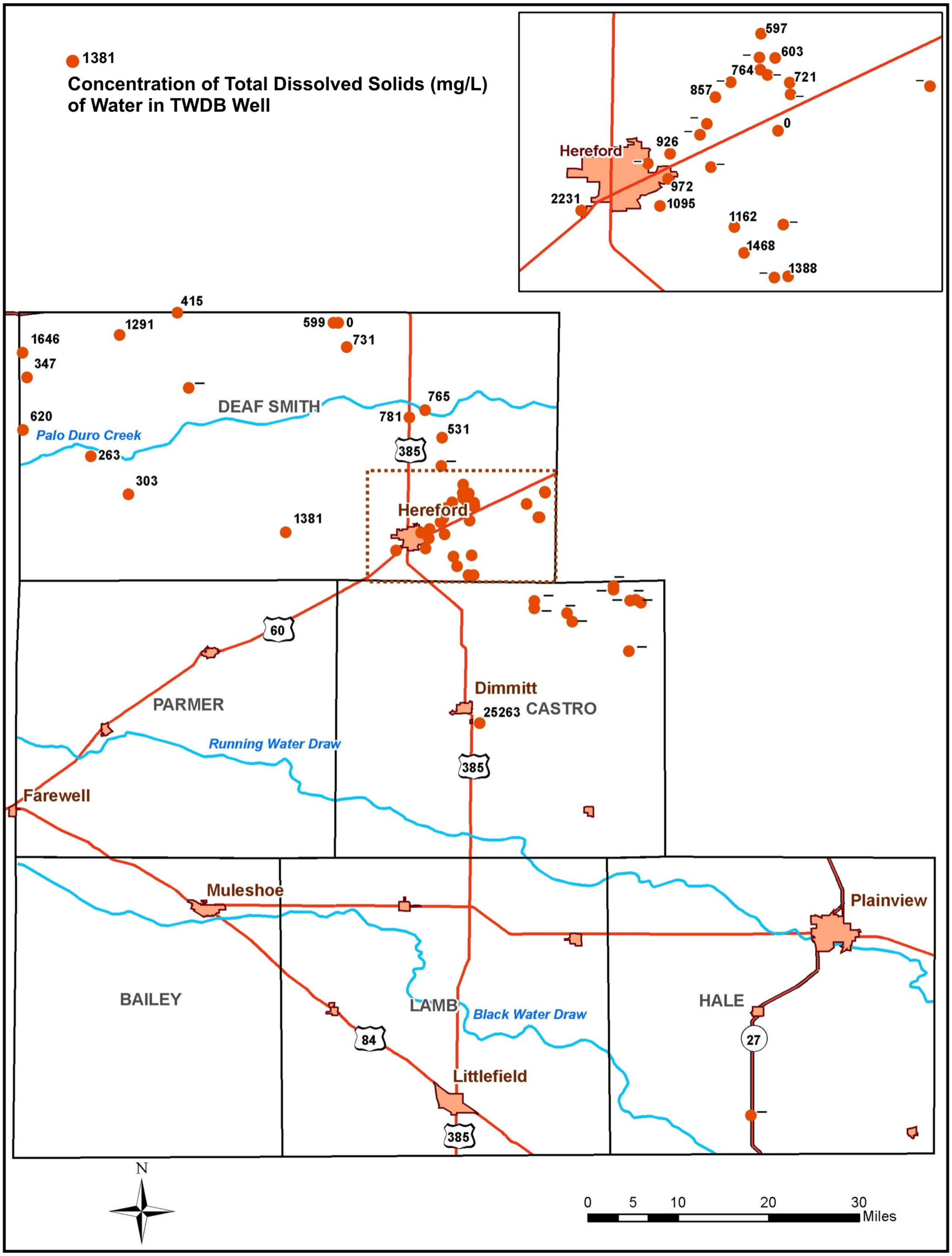


Figure 3.1-16. Salinity of Water from Dockum Water Wells in TWDB Database

5. Calculate the volume of sandstone by multiplying the thickness of the sandstone (step 4) by the areas estimated in step 1,
6. Calculate the volume of artesian head by the thickness between the potentiometric surface and above the top of the Upper Dockum and top of the Lower Dockum,
7. Estimate the average specific yield (drainable water) and storage coefficient (release of water under artesian pressure). The specific yield was taken from Bradley and Kalaswad (2003) and is equal to 0.065. The storage coefficient is an average of Dockum aquifer test of wells in Deaf Smith County, as published by Bradley and Kalawad (2003), which is approximately equal to 0.00007
8. Calculate volume of drainable water by multiplying the volume of the sandstone by the specific yield to get the volume of drainable water,
9. Calculate volume of artesian water by multiplying the volume of artesian head by the storage coefficient to get the volume of artesian water,
10. Sum the volumes of categories of Upper and Lower Dockum, salinity ranges and counties.

The greatest amount of groundwater with a salinity of 5,000 mg/L or less occurs in Deaf Smith County (Table 3.1-1). The Lower Dockum is much more favorable than the Upper Dockum. Bailey and Lamb Counties have a considerable volume of Dockum groundwater, but the salinity is estimated to be mostly greater than 20,000 mg/L. It is estimated that there are nearly 85 million (85,000,000) acft of groundwater in the Dockum in this six county area.

Bradley and Kalaswad (2003) also made calculations on the availability of groundwater in the Dockum, by county, for the High Plains. A comparison of the results show that the method used in this analysis produces 2.5 to 4.2 times more water in storage in the study area than calculated by Bradley and Kalaswad (2003). The major reason for the difference is in the estimated thickness of the sandstone. Bradley and Kalaswad (2003) only included the “Best Sandstone” and estimated its thickness to be 125 ft across the High Plains. The method of this analysis included all sandstones.

3.1.6 Potential Well Fields

Eight potential groundwater development projects (well fields) were selected and designed to provide information on estimated drawdown and cost to construct and operate. One of the projects would be located in south-central Deaf Smith County and the other one in the vicinity of Parmer, Castro and Lamb County lines (Figure 3.1-17). To evaluate the well fields for the projects, three levels of pumping were evaluated, including 0.2, 1, 3, and 10 million gallons per day (MGD) (224, 1,120, 3,360 and 11,200 acre-feet per year (acft/yr)).

**Table 3.1-1.
Volume of Groundwater in Upper and Lower Dockum,
by Salinity Ranges and County, in Study Area**

Counties	Salinity (Concentration of Total Dissolved Solids (mg/L)							
	<1,000	1,000-2,000	2,000-3,000	3,000-5,000	5,000-10,000	10,000-20,000	>20,000	All Ranges
Upper Dockum (acft)								
Deaf Smith	124,000	269,000	278,000	299,000	10,000	0	0	980,000
Parmer	0	0	0	234,000	281,000	663,000	255,000	1,433,000
Castro	0	0	0	65,000	426,000	815,000	1,801,000	3,107,000
Bailey	0	0	0	0	84,000	1,014,000	4,282,000	5,380,000
Lamb	0	0	0	0	0	0	3,184,000	3,184,000
Hale	12,000	13,000	16,000	43,000	159,000	555,000	289,000	1,087,000
Lower Dockum (acft)								
Deaf Smith	7,312,000	4,097,000	3,385,000	3,345,000	100,000	0	0	18,239,000
Parmer	0	0	0	2,211,000	2,976,000	3,399,000	1,180,000	9,766,000
Castro	0	0	0	458,000	1,815,000	2,615,000	4,719,000	9,607,000
Bailey	0	0	0	0	122,000	1,828,000	8,440,000	10,390,000
Lamb	0	0	0	0	0	0	11,006,000	11,006,000
Hale	235,000	373,000	515,000	1,207,000	2,449,000	3,894,000	1,733,000	10,406,000
Dockum (acft)								
Deaf Smith	7,436,000	4,366,000	3,663,000	3,644,000	110,000	0	0	19,219,000
Parmer	0	0	0	2,445,000	3,257,000	4,062,000	1,435,000	11,199,000
Castro	0	0	0	523,000	2,241,000	3,430,000	6,520,000	12,714,000
Bailey	0	0	0	0	206,000	2,842,000	12,722,000	15,770,000
Lamb	0	0	0	0	0	0	14,190,000	14,190,000
Hale	247,000	386,000	531,000	1,250,000	2,608,000	4,449,000	2,022,000	11,493,000

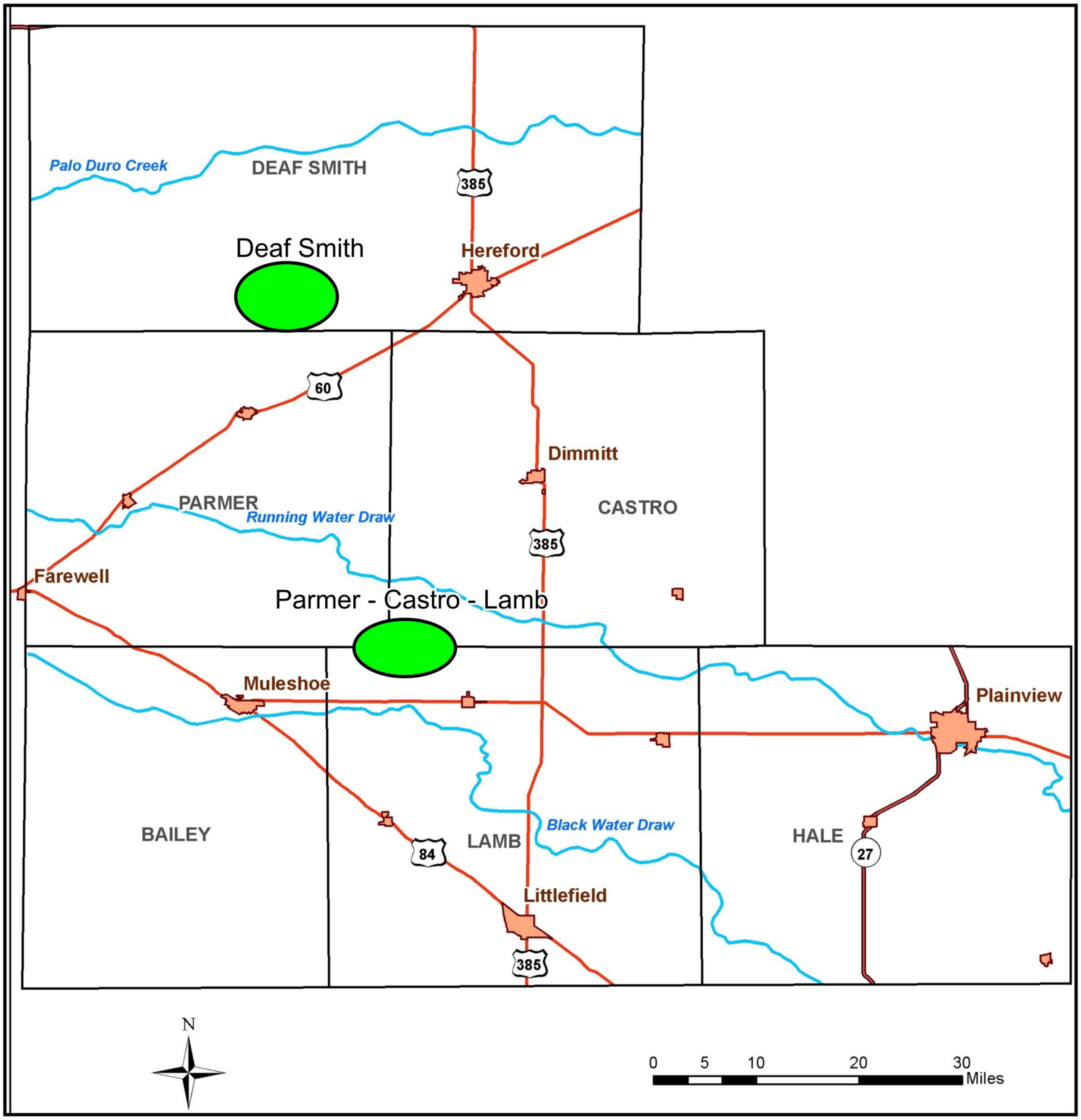


Figure 3.1-17. Location of Potential Well Fields

3.1.6.1 Well Field Model

The selected approach in estimating the drawdown from pumping wells was to develop an analytical well field model to calculate the cumulative drawdown (interference) of all wells operating continuously for fifty (50) years. Analytical well field models have the advantage of being able to represent exact well locations and also of being able to calculate the drawdown at any location. However, they have the disadvantage of requiring the aquifer to be represented as a single layer, in confined or unconfined conditions, and in an infinite extent.

The well field simulations were performed with the Aquifer Win32 software developed by Environmental Simulations, Inc.

3.1.6.2 Aquifer Properties in Well Fields

Key aquifer parameters that are needed to estimate aquifer drawdown and cost are transmissivities and storage coefficients. For the Deaf Smith County well field, the selected transmissivity is a median value for aquifer tests in Deaf Smith County (Bradley and Kalaswad (2003). This value is about 1,000 square feet/day (sqft/d). The value for the Parmer-Castro-Lamb well field is estimated to be 500 sqft/d, which is based on a comparison of the thickness of the sandstone in the Lower Dockum in the two well fields. For these transmissivity values, typical specific capacities of wells (discharge in gallons per minute divided by drawdown after an extended period) are 4.0 and 2.0 gpm/ft the Deaf Smith and Parmer-Castro-Lamb well fields, respectively. Assuming a 100 ft drawdown is acceptable, well yields would be 400 and 200 gpm. A storage coefficient of 0.00007 was used for both potential well fields.

3.1.6.3 Well Field Designs

With the well fields at two locations and pumping at four rates, eight designs were required. The number of wells and their average pumping rate (Table 3.2-1) are based on: maximum pumping rates of 400 and 200 gpm, well field operations at 0.2, 1, 3 and 10 MGD, a 25 percent contingency of extra wells, and an incremental number of wells.

For purposes of this report, the selected well field layout is one mile spacing between wells and generally on a square grid.

3.1.6.4 Estimated Quantity of Production and Drawdown

The selected time scale for the model simulations was 1-year intervals for the first 10 years and 5-year intervals for 50 years. The quantity of water produced, water levels, and drawdown were calculated at the end of each time interval. The conceptual design and assumptions of analytical well field models produce results that are best in the relatively short term. For long-term simulations, aquifer boundaries such as the limits of the aquifer, streams, and overlying and underlying aquifers become a factor. Some of these boundaries, such as the limit of the aquifer, will cause the analytical model to under predict the drawdown. Other boundaries, such as leakage from adjacent formations and streams, will reduce the predicted drawdown. For purposes of this study, results for the first ten years are believed to be reasonably accurate.

For the pumping levels of the well fields described above, estimated annual production (yield) from the Dockum Aquifer is Deaf Smith, Parmer, Castro, and/or Bailey counties for a 0.2 MGD well field is 224 acft/yr, for a 1 MGD well field is 1,120 acft/yr, for a 3 MGD well field is 3,360 acft/yr, for a 10 MGD well field is 11,200 acft/yr (Table 3.2-1). The salinity concentration of the water produced is expect to be in the range of 5,000 to 8,000 mg/L of total dissolved solids for the Deaf Smith well field and of 20,000 to 30,000 mg/L of total dissolved solids for the Parmer-Castro-Lamb well field. Costs to desalinate this water to public drinking water standards are presented in Section 3.3.

Drawdown maps at the end of 10 years of continuous pumping in the Deaf Smith and Parmer-Castro-Lamb for potential wells fields are shown in Figures 3.1-18 and 3.1-19, respectively. For the Deaf Smith well field pumping 0.2 MGD, the calculated drawdown at the supply well is about 25 ft. For the 1 MGD well field, the calculated drawdown was about 120 ft at the center of the well field and about 25 ft at a distance of about 20 miles. For the 3 and 10 MGD pumping well fields in the Deaf Smith County, the drawdown at a distance of about 20 miles was about 55 and 160 ft, respectively.

After 10 years of pumping of the Parmer-Castro-Lamb well field pumping at 0.2 MGD, the calculated drawdown is about 54 ft. For the 1 MGD well field, calculated drawdown was about 170 ft at the center of the well field and about 35 ft at a distance of about 20 miles. For the 3 and 10 MGD pumping in the Parmer-Castro-Lamb well fields, the drawdown at a distance of about 20 miles was about 110 and 350 ft, respectively.

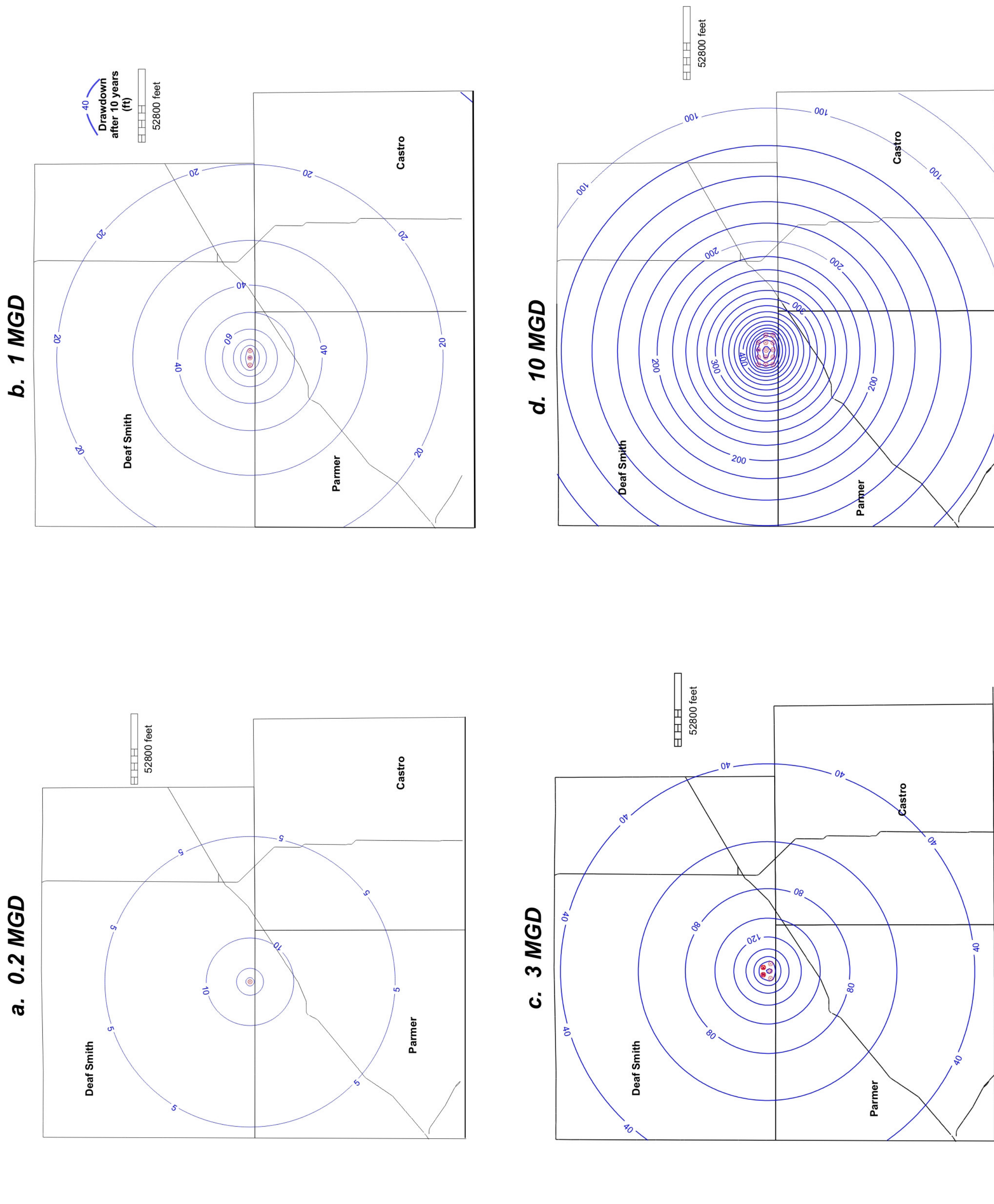


Figure 3.1-18. Drawdown from Potential Deaf Smith Well Field

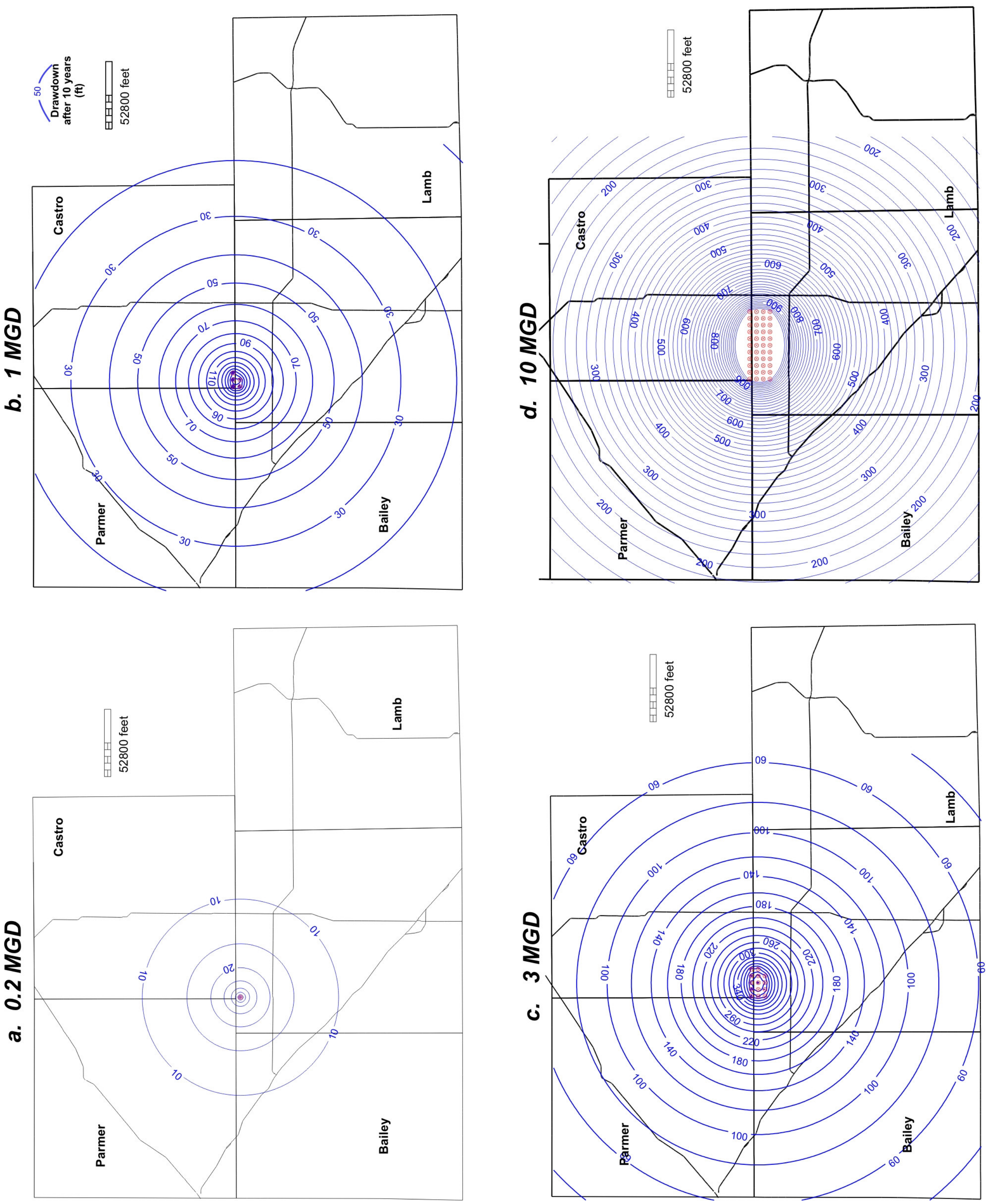


Figure 3.1-19. Drawdown from Potential Parmer-Castro-Lamb Well Field

Because of the transmissivity of the aquifer in the Deaf Smith well field is greater than in the Parmer-Castro-Lamb well field, one can expect that the cone of depression in the center of the Deaf Smith well field to be less than the Parmer-Castro-Lamb well field, but would extend over a much larger area.

To illustrate the trend in groundwater levels attributed to these well fields, the calculated drawdown at the center and at the northern and western edges of the well field were tabulated and plotted (Figures 3.1-20 and 3.1-21). Some of the findings from a study of these hydrographs include: (1) the drawdown is much greater for higher pumping rates, (2) the drawdown for all times is much greater in the Parmer-Castro-Lamb well field than in the Deaf Smith well field, (3) rate of decline in water levels decreases over time, (4) the drawdown in the vicinity of the well field at the end of year 1 is 50-65 percent of the amount that would accrue in 50 years of operation, and (5) an additional drawdown of about 25 percent can be expected from year 10 to year 50. Aquifer boundary conditions could affect the overall shape and magnitude of the drawdown hydrographs.

It is important to note that the calculated drawdown in the Parmer-Castro-Lamb well field at the 10 MGD rate reaches the estimated depth of wells in the center of the well field by year 20. Since, for operational reasons, water levels probably should be at least 200 ft above the well depths, with well depths in the Parmer-Castro-Lamb area estimated to be about 1,400 ft, the operational limit would be reached in about 10 years.

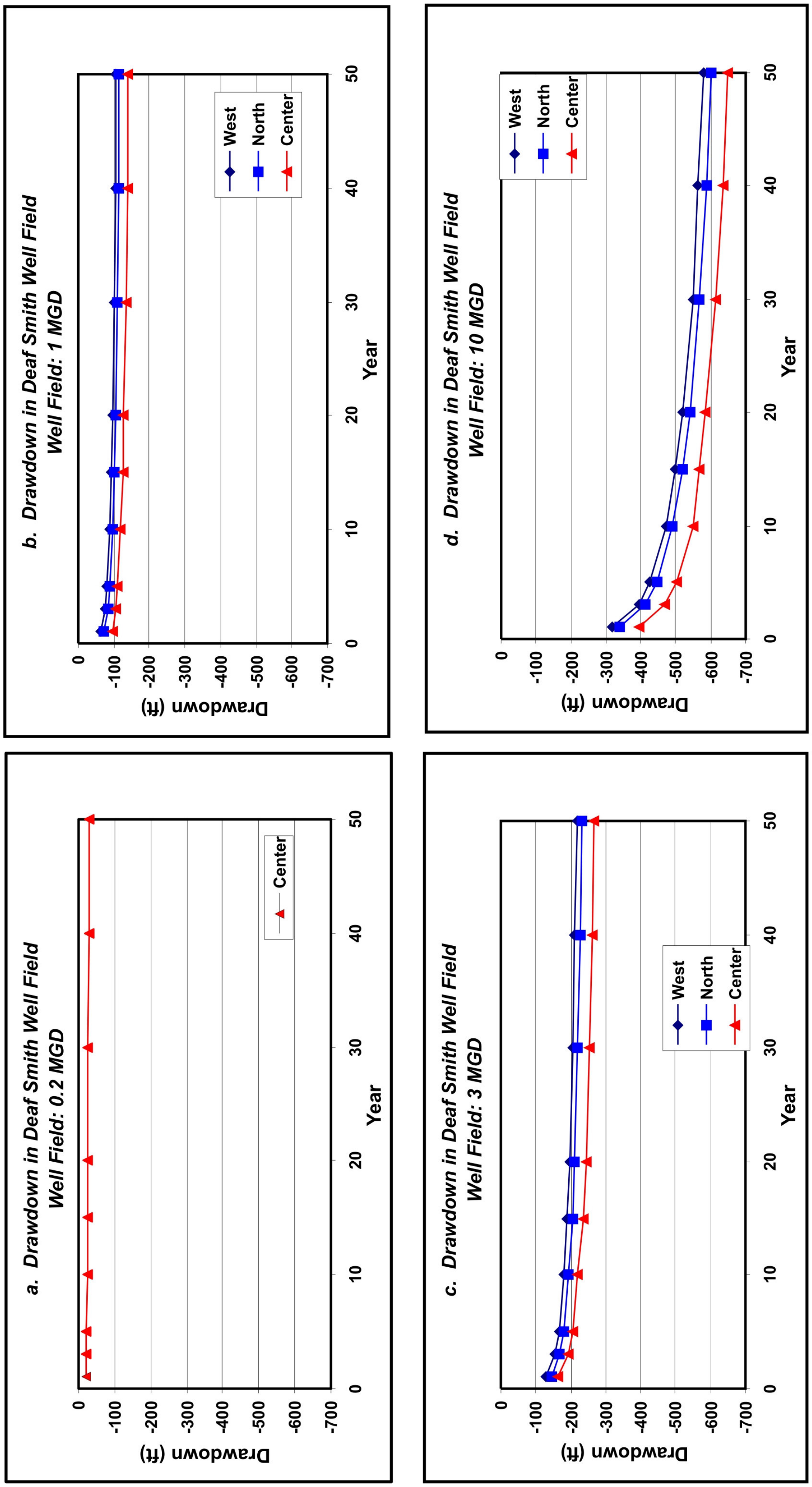


Figure 3.1-20. Drawdown Hydrographs for Monitoring Wells at Center, Northern Edge, and Western Edge of Potential Deaf Smith Well Field for 0.2, 1, 3, and 10 MGD

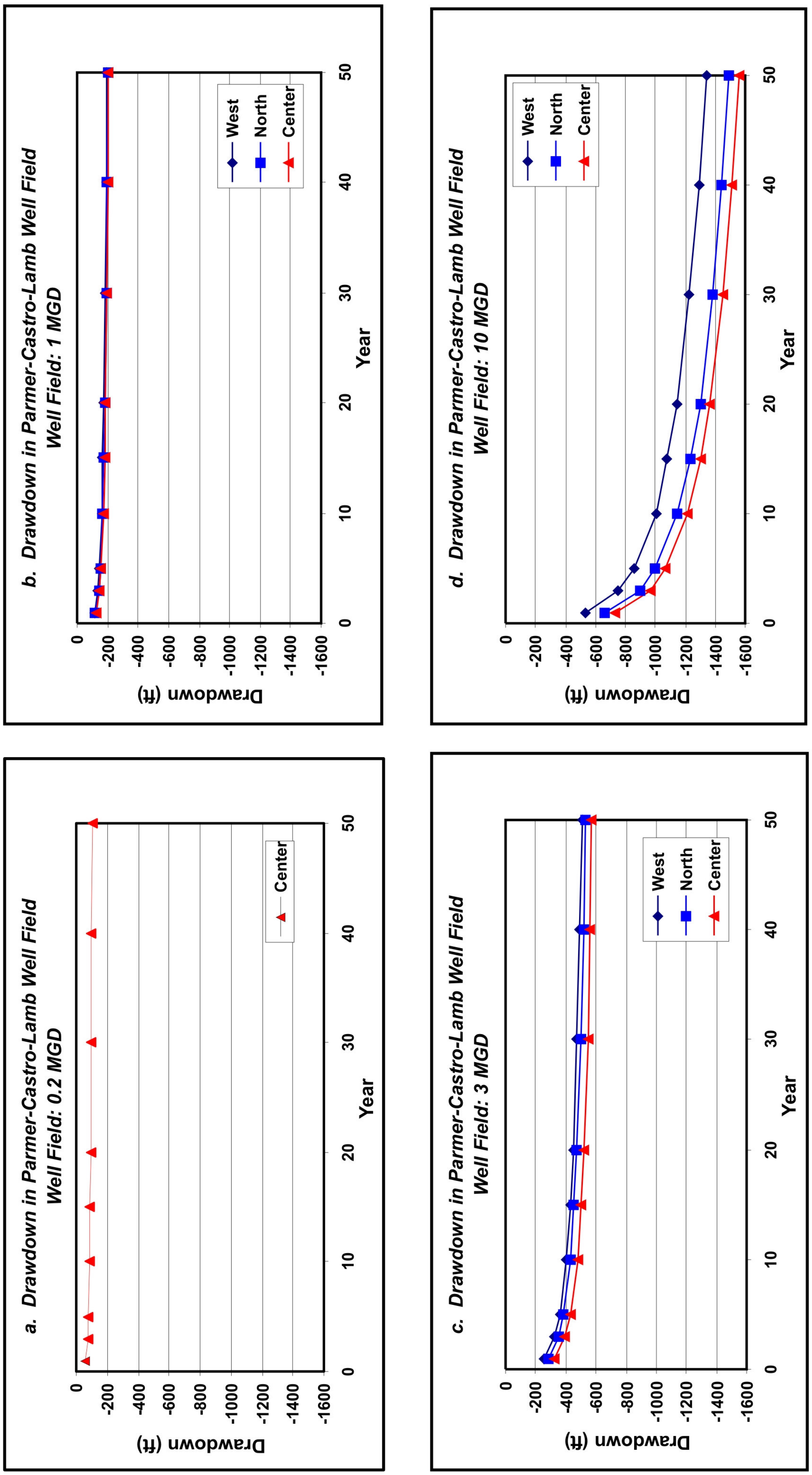


Figure 3.1-21. Drawdown Hydrographs for Monitoring Wells at Center, Northern Edge, and Western Edge of Potential Parmer-Castro-Lamb Well Field for 0.2, 1, 3, and 10 MGD Projects

3.2 Estimated Costs to Obtain Groundwater from Dockum Aquifer

Preliminary engineering designs for the wells, well field collection pipelines and ground storage at the terminal were prepared for the eight potential groundwater development projects (well fields) described in section 3.1. These designs do not include desalination and the disposal of concentrate in this water treatment process. As stated in section 3.1, one of these projects is assumed to be located in south-central Deaf Smith County and the other one in the vicinity of Parmer, Castro and Lamb County lines. To test the size of the well fields for the projects, four levels of pumping were evaluated, including 0.2, 1, 3 and 10 MGD, or 224, 1,120, 3,360 and 11,200 acft/yr, respectively.

3.2.1 Preliminary Well Field Designs

For purposes of this report, the well layout is on one (1) mile centers and generally on a square grid. As with the well field model, the number of wells in a well field includes a contingency of extra wells at 25 percent, except for the smallest well field (0.2 MGD), where no contingency is included. The number of wells in each of the eight well fields was listed in the previous section in Table 3.2-1. The placement of well screen is based on the most productive water bearing zones (sandstone) being near the bottom of the Lower Dockum. For purposes of this report, well depths are estimated to be 1,200 ft for the Deaf Smith and 1,400 ft for the Parmer-Castro-Lamb well field. The wells are designed to public drinking water standards instead of construction practices common for irrigation wells, in order to protect the Ogallala from an intrusion of poor quality water from the Dockum, leakage of Ogallala water into the Dockum, and contact with potentially corrosive water,. The well field pipelines form a manifold to collect water from each well and to deliver it to a terminal ground storage tank a half (0.5) mile north of the well field. The pipe diameter was determined on the basis of the amount of water flowing in the pipeline and keeping head losses low enough to not require pump station(s) within the well field. An example of well field layout is provided in Figure 3.2-1 for the 3 MGD Parmer-Castro-Lamb well field. Terminal storage is needed to balance the water demand and supply, and is assumed to be about a half day of water production.

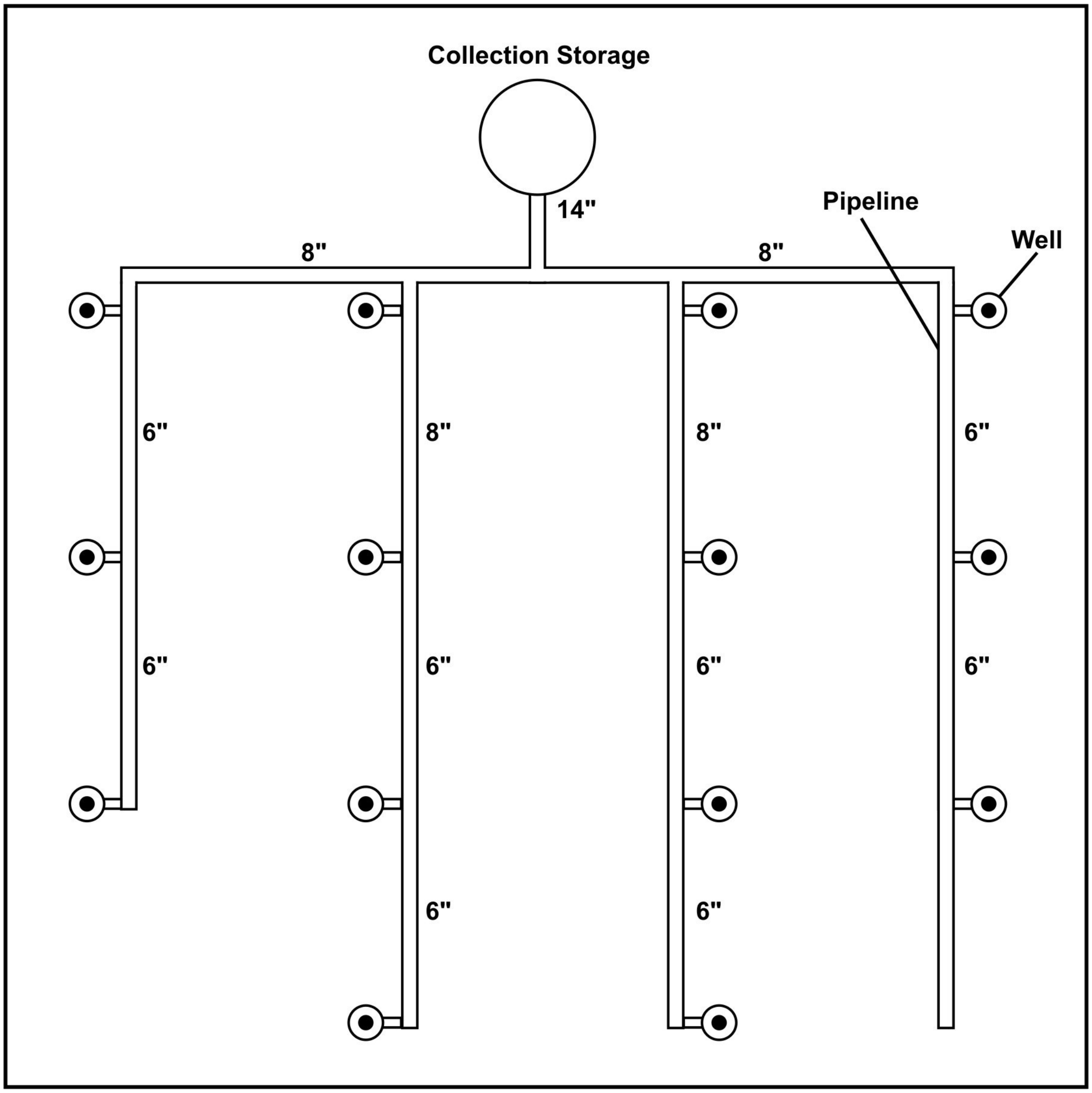


Figure 3.2-1. Example Well Field Layout and Design Using 3 MGD Parmer-Castro-Lamb Project

Table 3.2-1.
Selected Features of the Eight Potential Well Fields

System Components and Sizes	Well Field Locations							
	Deaf Smith				Parmer-Castro-Lamb			
Capacity (MGD)	0.2	1	3	10	0.2	1	3	10
Numbers of Wells	1	3	7	22	1	5	14	44
Well Depths (ft)	1,200	1,200	1,200	1,200	1,400	1,400	1,400	1,400
Max. Well Yields (gpm)	150	400	400	400	150	200	200	200
Ave. Well Yieds (gpm)	139	231	297	315	139	139	149	158
Pipeline Diameter (in)	Pipeline Length (miles)							
6	0.5	2			0.5	3	8	6
8			6	4		1	4	12
10		0.5		4		0.5		12
12			1	8			1	10
14			0.5	4			0.5	
16								2
20				1				1
27				0.5				0.5
Total Pipeline Length (mi)	0.5	2.5	7.5	21.5	0.5	4.5	13.5	43.5
Ground Storage (MG)	0.1	0.5	2	5	0.1	0.5	2	5
Water Treatment	See Section 3.3							

3.2.2 Cost Estimates for Untreated Dockum Water

Preparation of cost estimates include capital cost, such as wells and pipelines, other project costs, such as engineering, contingencies and environmental surveys, and annual cost such as operation and maintenance and power, and are for Dockum water at the location of the well fields (i.e., untreated and without desalination). Costs of desalination and concentrate disposal are presented in Section 3.3. For comparison purposes, the unit cost of the water is calculated.

Major assumptions used in calculating these costs include:

- Based on recent surveys by Real Estate Center at Texas A&M University, land costs are estimated to be $600 per acre,
- Contingency is 30 percent for pipelines and storage tanks and 35 percent for wells,

- Well pump and power requirements are based on drawdown at the end of 10 years,
- Interest on debt will be at 6 percent per year for 30 year,
- Power cost will be at $0.06 per KW-Hr,
- Water treatment and disposal of concentration are included in Section 3.3,
- Environmental and Archeological surveys and mitigation will be required, and
- Duration of construction will be 2 years.

A summary of the cost for the two well fields pumping at four different rates is shown in Table 3.2-2. A comparison of the two well fields shows the least expensive water in terms of unit cost of raw water is about $305 per acft for a 3 MGD project in Deaf Smith County. The least expensive project in the Parmer-Castro-Lamb well field is $441 per acft for a 3 MGD project. Unit cost of water in the Parmer-Castro-Lamb well field is about 4, 27, 45, and 52 percent higher than the Deaf Smith well field for 0.2, 1, 3, and 10 MGD capacities. Of interest, there is an economy of scale when going from 1 to 3 MGD; however, the cost of longer and larger pipelines and increased power rewuirements causes the 10 MGD projects to be more expensive than the 3 MGD project in the same well field.

When water treatment cost are considered, the Parmer-Castro-Lamb well field is expected to be much more expensive that the Deaf Smith well field because of the salinity of water in the Parmer-Castro-Lamb well field is much, much higher than water from the Deaf Smith well field.

It's important to note that the calculated drawdown in the Parmer-Castro-Lamb well field at the 10 MGD rate exceeds the maximum depth of the aquifer in the center of the well field at the end of 10 years. Thus, a 10 MGD well field in the Parmer-Castro-Lamb area should not be considered for a long-term viable water supply strategy without further study that includes consideration of a transition of aquifer storage properties from artesian to water table and groundwater modeling with variable density capability. The groundwater model MODFLOW is capable of representing the transition of storage properties. However, it assumes groundwater to have the density of freshwater; thus, it does not simulate a variable density of groundwater and cannot be formulated to be a technically sound representation of the Dockum within the ranges of depths and salinities expected to be encountered in the Parmer-Castro-Lamb area.

Table 3.2-2.
Cost Estimates for Eight Potential Well Fields

System Components and Sizes	Well Field Locations							
	Deaf Smith				Parmer-Castro-Lamb			
Capacity (MGD)	0.2	1	3	10	0.2	1	3	10
Yield (scft/yr)	224	1,120	3,360	11,200	224	1,120	3,360	11,200
Capital Costs	1,000s of Dollars							
Wells	409	1,720	4,048	12,831	460	2,625	6,510	20,901
Pipelines	180	737	1,458	5,741	180	853	2,683	10,427
Ground Storage	121	412	1,187	2,422	121	412	1,187	2,422
Power Connections	10	30	72	318	10	50	140	440
Total Capital Costs	720	2,899	6,765	21,312	771	3,940	10,520	34,190
Other Costs	1,000s of Dollars							
Engr. Legal, & Contingencies	251	1,010	2,358	7,426	268	1,373	3,661	11,898
Env. Arch. & Mitigation	25	92	172	565	25	120	356	1,142
Interest During Construction	80	322	746	2,351	86	437	1,167	3,792
Total Project Costs	1,076	4,323	10,041	31,654	1,150	5,870	15,704	51,022
Annual Costs	1,000s of Dollars							
Debt Service	78	315	731	2,306	84	428	1,144	3,719
O & M	7	29	68	213	8	39	105	342
Power	13	65	227	996	10	53	233	1,266
Total Annual Costs	98	409	1,026	3,515	102	520	1,482	5,327
Unit Costs	(Dollars Per Acre-Foot)							
Unit Cost ($/acft)	438	365	305	314	455	464	441	476

3.3 Estimated Costs to Desalt Groundwater from the Dockum Aquifer

Interest in desalination technology has recently increased as a result of advances in process technology and the growing demand for reliable water sources in water-short areas. Increasingly, water suppliers are using desalination technology to replace and/or supplement traditional water sources, thereby improving water quality and supply system reliability. Though desalination system capital and operating costs still exceed the costs of traditional treatment systems, improvements in the longevity, reliability, and efficiency of desalination process components has narrowed this difference in recent years.

The following sections describe operational and regulatory considerations associated with desalting groundwater in Bailey, Castro, Deaf Smith, Hale, and Parmer Counties of the Llano Estacado Water Planning Region. Engineering and cost analyses include all facilities required for the production of potable water and disposal of concentrate waste at a site adjacent to the well fields from which the brackish water would be obtained. This evaluation does not include the design and cost of finished water transmission facilities (pump stations, pumps, and pipelines) to move the desalted water to a point or points of use, since the location of use is not known at this time.

3.3.1 Desalination System Design

Three principal techniques or technologies are used to separate dissolved solids from water, including reverse osmosis (RO), electrodialysis reversal, and thermal distillation. RO, the least costly and most widely used technique, desalts water by the application of pressure to drive the feed water through a semi-permeable membrane, and is the method for which costs are estimated in this study.

3.3.1.1 Desalination Process

During the RO process, a pressure or driving force that is higher than the combined resistance of the membrane and the osmotic pressure of water is applied to the feed water to push the water through the semi-permeable membrane barrier. This process separates the feed water into two streams: (1) permeate and (2) concentrate. Permeate is the demineralized product water that has passed through the membrane; conversely, the concentrate stream contains the dissolved solids and ions that have been removed from the feed stream. Water recovery is an operational condition that characterizes the relative magnitude of these streams and is defined as the percent of feed water that passes through the RO system as permeate. The desalination recovery rate generally decreases as the salinity of water to be treated increases. For example, for groundwater with 1,500 mg/L of TDS, a desalination recovery rate of 80 percent was estimated for this evaluation, meaning that 20 percent of the feed water was estimated to be discharged as concentrate (Table 3.3-1). The recovery rates for water with TDS levels of 3,000 mg/L, 5,000 mg/L, and 20,000 mg/L are also shown in Table 3.3-1.

As discussed in previous sections, the total dissolved solids (TDS) concentration of water in the Dockum Aquifer in the six-county study area ranges from less than 1,000 mg/L to more than 20,000mg/L. For the development of general desalination cost estimates, TDS concentrations ranging from 1,500 to 20,000 mg/L were considered, in order to reflect potential spatial or temporal salinity fluctuations within the study area. Groundwater production capacities of brackish groundwater from the Dockum Aquifer of 0.2 MGD, 1 MGD, 3 MGD, and 10 MGD were evaluated in this analysis. In Table 3.3-1, the feed water and concentrate stream flow rates associated with these raw groundwater production capacities are presented. The TDS concentration of the concentrate brine is substantially higher than that of the feed water. Assuming 9 percent rejection of dissolved salts, the concentrate stream TDS concentration for a groundwater with 3,000 mg/L of TDS is calculated to be approximately 12,000 mg/L, while TDS concentration for a groundwater with 20,000 mg/L is approximately 50,000 mg/L (Table 3.3-1). For comparison, the required secondary Maximum Contaminant Level (MCL) for TDS for public water supply is 1,000 mg/L.

Given the high quality of the desalted product water, blending strategies can be used to reduce treatment costs. The quantity of raw, undesalted groundwater that can be blended back with RO treated (desalted) water decreases as the feed water TDS increases. The target finished water TDS concentration of 500 mg/L was assumed in order to determine the blending ratio for each starting groundwater TDS level. For groundwater with 3,000 mg/L of TDS this evaluation assumes that the desalted water will be blended with untreated brackish water to produce a blended finished water that is 85 percent desalted water and 15 percent brackish groundwater.

An effective and reliable pretreatment system is essential to the successful operation of a desalination facility. RO membrane systems require high quality feed water to reduce the magnitude and frequency of fouling, the time between cleanings, and extend membrane life. To ensure the supply of high quality feed water, a cartridge filtration system and chemical pretreatment system (e.g., acid antiscalant) will be needed. Chemical post treatment, specifically disinfection, will also be necessary for compliance with state and federal finished water quality requirements. Costs are included for these facilities and chemicals.

Table 3.3-1.
Desalination Process Flow Summary

Groundwater TDS, mg/l	1,500	3,000	5,000	20,000
Undesalted Blend Water, %	30%	15%	10%	0%
Desalination Recovery Rate, %	80%	75%	70%	60%
TDS of RO Concentrate, mg/l	7,500	12,000	16,667	50,000
Brackish Well Water Supply = 0.2 MGD (224 acft/yr)				
Concentrate, MGD	0.03	0.04	0.05	0.08
Desalinated Water, MGD	0.11	0.13	0.13	0.12
Total Blended Water Supply, MGD	0.17	0.16	0.15	0.12
Brackish Well Water Supply = 1 MGD (1,121 acft/yr)				
Concentrate, MGD	0.14	0.21	0.27	0.40
Desalinated Water, MGD	0.55	0.64	0.64	0.60
Total Blended Water Supply, MGD	0.86	0.79	0.73	0.60
Brackish Well Water Supply = 3 MGD (3,363 acft/yr)				
Concentrate, MGD	0.4	0.6	0.8	1.2
Desalinated Water, MGD	1.7	1.9	1.9	1.8
Total Blended Water Supply, MGD	2.6	2.4	2.2	1.8
Brackish Well Water Supply = 10 MGD (11,210 acft/yr)				
Concentrate, MGD	1.4	2.1	2.7	4.0
Desalinated Water, MGD	5.6	6.4	6.3	6.0
Total Blended Water Supply, MGD	8.6	7.9	7.3	6.0

3.3.1.2 Desalination Estimated Costs

The estimated costs for a desalination facility at the aforementioned capacities are presented in Tables 3.3-2 through 3.3-5. Estimates include the cost of the RO membrane system, standard pretreatment system consisting of cartridge filters and acid addition, post treatment disinfection, and finished water storage facilities. The finished water storage facility cost estimates are based on providing a ground storage tank sized to hold 10 percent of the daily finished water quantity. Costs associated with the delivery of finished water to the end user (i.e., the finished water transmission pump stations, pumps, and pipelines) are not included in the estimate. Costs for concentrate disposal are presented in Section 3.3.2. In developing these costs, it is assumed that the desalination and concentrate disposal facilities will be constructed adjacent to the well field. The estimates are organized and based on the untreated groundwater production capacities of 0.2 MGD, 1 MGD, 3 MGD, and 10 MGD. Available project yield for each groundwater quality (as represented by TDS concentration) is dependent on the desalination recovery rate and blending quantities presented in Table 3.3-1. Higher finished water yields are available for the lower TDS groundwaters because less water is lost as desalination concentrate. Total treated water costs increase for higher TDS groundwater due to the lower recovery and

Table 3.3-2.
Estimated Desalination Costs for Groundwater with TDS of 1,500 mg/L

Item	Desalination Plant Size (MGD)			
	0.2	*1*	*3*	*10*
Costs in 1,000s of Dollars	**($1,000)**	**($1,000)**	**($1,000)**	**($1,000)**
Capital Costs				
Ground Storage Tank	$173	$621	$1,443	$3,624
Desalination Water Treatment Plant	$709	$1,774	$3,668	$8,783
Total Capital Cost	**$882**	**$2,395**	**$5,111**	**$12,407**
Engineering, Legal Costs and Contingencies	$309	$838	$1,789	$4,342
Environmental & Archaeology Studies and Mitigation	$5	$7	$10	$17
Land Acquisition and Surveying (6 acres)	$6	$8	$11	$19
Interest During Construction (2 years)	$97	$260	$554	$1,343
Total Project Cost	**$1,299**	**$3,508**	**$7,475**	**$18,128**
Annual Costs				
Debt Service (6 percent, 30 years)	$94	$255	$543	$1,317
Operation and Maintenance				
Ground Storage Tank	$2	$6	$14	$36
Water Treatment Plants	$62	$206	$493	$1,419
Total Annual Cost	**$159**	**$467**	**$1,050**	**$2,772**
Available Project Yield (acft/yr)	193	964	2,899	9,664
Annual Cost of Water ($ per acft)	$825	$484	$362	$287
Annual Cost of Water ($ per 1,000 gallons)	$2.53	$1.49	$1.11	$0.88

blending rates. Higher feed pressures and better materials of construction required for higher TDS water, results in increased desalination costs of the higher TDS water.

For desalination facilities to desalt brackish groundwater having 1,500 mg/L of TDS, total project costs (capital plus engineering, legal, contingencies, land acquisition, surveying and interest during construction) are $1,299,000 for a 0.2 MGD facility (Table 3.3-2). The 0.2 MGD facility would produce 193 acft of desalted water per year at a desalination cost of $825 per acft, or $2.53 per 1,000 gallons, not including cost of obtaining the brackish water, nor the cost of concentrate disposal. Total project costs for a 3 MGD facility are $7,475,000, and for a 10 MGD facility are $18,128,000 (Table 3.3-2), with production of 2,899 and 9,664 acft/yr of water, respectively, at costs of $1.11 and $0.88 per 1,000 gallons, respectively (Table 3.3-2).

Table 3.3-3.
Estimated Desalination Costs for Groundwater with TDS of 3,000 mg/L

Item	Desalination Plant Size (MGD)			
	0.2	*1*	*3*	*10*
Costs in 1,000s of Dollars	**($1,000)**	**($1,000)**	**($1,000)**	**($1,000)**
Capital Costs				
Ground Storage Tank	$163	$579	$1,346	$3,394
Desalination Water Treatment Plant	$743	$1,948	$3,994	$9,867
Total Capital Cost	**$906**	**$2,527**	**$5,340**	**$13,261**
Engineering, Legal Costs and Contingencies	$317	$885	$1,869	$4,642
Environmental & Archaeology Studies and Mitigation	$5	$7	$10	$17
Land Acquisition and Surveying (6 acres)	$6	$8	$11	$19
Interest During Construction (2 years)	$99	$275	$579	$1,436
Total Project Cost	**$1,333**	**$3,702**	**$7,809**	**$19,375**
Annual Costs				
Debt Service (6 percent, 30 years)	$97	$269	$567	$1,407
Operation and Maintenance				
Ground Storage Tank	$2	$6	$13	$34
Water Treatment Plants	$68	$226	$550	$1,609
Total Annual Cost	**$167**	**$501**	**$1,130**	**$3,050**
Available Project Yield (acft/yr)	177	883	2,651	8,835
Annual Cost of Water ($ per acft)	$946	$567	$426	$345
Annual Cost of Water ($ per 1,000 gallons)	$2.90	$1.74	$1.31	$1.06

For desalination facilities to desalt brackish groundwater having 3,000 mg/L of TDS, total project costs (capital plus engineering, legal, contingencies, land acquisition, surveying and interest during construction) are $1,333,000 for a 0.2 MGD facility (Table 3.3-3). The 0.2 MGD facility would produce 177 acft of desalted water per year at a desalination cost of $946 per acft, or $2.90 per 1,000 gallons, not including cost of obtaining the brackish water, nor the cost ofconcentrate disposal. Total project costs for a 3 MGD facility are $7,809,000, and for a 10 MGD facility are $19,375,000 (Table 3.3-3), with production of 2,651 and 8,835 acft/yr of water, respectively, at costs of $1.31 and $1.06 per 1,000 gallons, respectively (Table 3.3-3).

Table 3.3-4.
Estimated Desalination Costs for Groundwater with TDS of 5,000 mg/L

Item	Desalination Plant Size (MGD)			
	0.2	***1***	***3***	***10***
Costs in 1,000s of Dollars	**($1,000)**	**($1,000)**	**($1,000)**	**($1,000)**
Capital Costs				
Ground Storage Tank	$155	$546	$1,267	$3,198
Desalination Water Treatment Plant	*$840*	$2,061	$4,214	$10,401
Total Capital Cost	***$995***	**$2,607**	**$5,481**	**$13,599**
Engineering, Legal Costs and Contingencies	*$348*	$912	$1,918	$4,759
Environmental & Archaeology Studies and Mitigation	*$5*	$7	$10	$17
Land Acquisition and Surveying (6 acres)	*$6*	$8	$11	$18
Interest During Construction (2 years)	$109	$283	$594	$1,472
Total Project Cost	**$1,463**	**$3,817**	**$8,014**	**$19,865**
Annual Costs				
Debt Service (6 percent, 30 years)	$106	$277	$582	$1,442
Operation and Maintenance				
Ground Storage Tank	$2	$5	$13	$32
Water Treatment Plants	$74	$244	$607	$1,789
Total Annual Cost	**$182**	**$526**	**$1,202**	**$3,263**
Available Project Yield (acft/yr)	164	818	2,446	8,153
Annual Cost of Water ($ per acft)	$1,112	$643	$491	$400
Annual Cost of Water ($ per 1,000 gallons)	$3.41	$1.97	$1.51	$1.23

For desalination facilities to desalt brackish groundwater having 5,000 mg/L of TDS, total project costs (capital plus engineering, legal, contingencies, land acquisition, surveying and interest during construction) are $1,463,000 for a 0.2 MGD facility (Table 3.3-4). The 0.2 MGD facility would produce 164 acft of desalted water per year at a desalination cost of $1,112 per acft, or $3.41 per 1,000 gallons, not including cost of obtaining the brackish water, nor the cost of concentrate disposal. Total project costs for a 3 MGD facility are $8,014,000, and for a 10 MGD facility are $19,865,000 (Table 3.3-4), with production of 2,446 and 8,153 acft/yr of water, respectively, at costs of $1.51 and $1.23 per 1,000 gallons, respectively (Table 3.3-4).

Table 3.3-5.
Estimated Desalination Costs for Groundwater with TDS of 20,000 mg/L

Item	Desalination Plant Size (MGD)			
	0.2	1	3	10
Costs in 1,000s of Dollars	**($1,000)**	**($1,000)**	**($1,000)**	**($1,000)**
Capital Costs				
Ground Storage Tank	$136	$470	$1,090	$2,786
Desalination Water Treatment Plant	$987	$2,364	$4,708	$10,996
Total Capital Cost	**$1,123**	**$2,834**	**$5,798**	**$13,782**
Engineering, Legal Costs and Contingencies	$393	$992	$2,029	$4,824
Environmental & Archaeology Studies and Mitigation	$5	$7	$10	$16
Land Acquisition and Surveying (6 acres)	$6	$8	$11	$17
Interest During Construction (2 years)	$123	$308	$628	$1,492
Total Project Cost	**$1,650**	**$4,149**	**$8,476**	**$20,131**
Annual Costs				
Debt Service (6 percent, 30 years)	$120	$301	$615	$1,462
Operation and Maintenance				
Ground Storage Tank	$1	$5	$11	$28
Water Treatment Plants	$87	$302	$780	$2,352
Total Annual Cost	**$208**	**$608**	**$1,406**	**$3,842**
Available Project Yield (acft/yr)	135	673	2,018	6,726
Annual Cost of Water ($ per acft)	$1,546	$903	$697	$571
Annual Cost of Water ($ per 1,000 gallons)	$4.74	$2.77	$2.14	$1.75

For desalination facilities to desalt brackish groundwater having 20,000 mg/L of TDS, total project costs (capital plus engineering, legal, contingencies, land acquisition, surveying and interest during construction) are $1,650,000 for a 0.2 MGD facility (Table 3.3-5). The 0.2 MGD facility would produce 135 acft of desalted water per year at a desalination cost of $1,546 per acft, or $4.74 per 1,000 gallons, not including cost of obtaining the brackish water, nor the cost of concentrate disposal. Total project costs for a 3 MGD facility are $8,476,000, and for a 10 MGD facility are $20,131,000 (Table 3.3-5), with production of 2,018 and 6,726 acft/yr of water, respectively, at costs of $2.14 and $1.75 per 1,000 gallons, respectively (Table 3.3-5).

3.3.2 Concentrate Disposal Methods

The chemical content and concentration of the concentrate waste stream principally depends on source water quality and the operating conditions. Desalination concentrate reflects the characteristics of the raw source water, although at a more concentrated level, and is not hazardous unless the concentrate stream contains appreciable concentrations of hazardous contaminants, such as radioactive elements. Information about the Dockum Aquifer does not indicate that there are hazardous contaminants present.

Disposal of desalination concentrate can present regulatory and operational challenges. The concentrate disposal system should be designed to mitigate any adverse effects of the discharge and facilitate regulatory compliance, while minimizing associated capital and operational costs. Key factors for consideration include the chemical composition and the daily volume of waste to be discharged. The following alternatives have commonly been used to dispose of concentrate wastes:

- Surface water discharge;
- Solar evaporation ponds;
- Deep well injection;
- Land application (spray irrigation);
- Disposal to sewer (wastewater treatment plant processing);
- Zero liquid discharge (mechanical evaporation).

Conditions in the area of interest do not justify the consideration of all the aforementioned concentrate disposal candidates. The two least complex solutions, surface water discharge and sewer disposal, are not viable alternatives because adequate receiving waters and wastewater treatment facilities do not exist in the study area. Land application via spray irrigation is not an advantageous solution due to the potential for environmental degradation resultant from the inevitable accumulation of salts in the receiving soil. More specifically, it is expected that the accrual of salts will exceed the toxicity threshold of the receiving vegetation and possibly contaminate groundwater sources if the water table is close to the surface. Zero liquid discharge utilizing mechanical evaporation is feasible from a constructability perspective, but due to high capital and operations cost it is prohibitive from an economic perspective. Environmental conditions including geological and meteorological considerations do warrant evaluation of solar evaporation and deep well injection strategies. Solar evaporation ponds and deep well injection disposal methods are described and cost estimates are provided below for: (1) solar evaporation , and (2) deep well injection methods for the desalination plant sizes and TDS levels listed in Table 3.3-1.

3.3.2.1 Solar Evaporation Ponds – Method and Costs

Solar ponds function by separating dissolved salts from the concentrate liquid through evaporation. These beds are relatively simple to construct, maintain, and clean and require no mechanical equipment other than pumps to transfer the concentrate to the ponds. Impervious liners (clay or synthetic membranes) are required to prevent leakage and the contamination of underlying groundwater. Predictably, this technique is most appropriate for small concentrate flows in arid regions with high evaporation rates and low land costs, since low evaporation rates and/or high concentrate disposal rates significantly increase the requisite evaporation area, thereby significantly increasing the cost of this disposal alternative.

Sizing of evaporation ponds primarily depends on climatic conditions, the concentrate discharge rate and concentration, and regulatory requirements. Ponds must have the capacity to accommodate concentrate disposal surges, precipitated salts, rainfall, and wave action. The evaporation and precipitation rates for this study area were estimated by evaluating 40 years of data collected at Lake Meredith, near Amarillo, Texas. A net evaporation rate of approximately 30 inches per year was determined after applying correction factors to account for the reduced evaporation potential of large bodies of high salinity water. As shown in Table 3.3-1, the salinity, or TDS, of the concentrate for a raw groundwater source with 1,500 mg/l of TDS and a recovery rate of 80 percent was estimated to be 7,500 mg/L, assuming 98 percent rejection of the source water TDS. The concentrate TDS for groundwater with higher salinities was estimated in the same manner with the results as shown in Table 3.3-1. The salinity within the evaporation ponds will be higher than the influent TDS concentration due to evaporation. A properly constructed impervious liner should be capable of containing the concentrate, but a National Pollution Disposal Elimination System (NPDES) permit may still be needed to avoid the effort of conclusively proving that the ponds do not leak.

Tables 3-6 through 3-9 show the estimated land surface area and associated costs for evaporation ponds to dispose of concentrate from desalination facilities treating groundwater with flows and qualities that are summarized in Table 3.3-1. Costs were estimated using a

Table 3.3-6.
Estimated Evaporation Pond Surface Area and Costs for Concentrate Disposal from RO Desalination of Brackish Groundwater of 1,500 mg/L of TDS for 0.2 MGD, 1 MGD, 3 MGD, and 10 MGD Sized Desalination Plants

	Desalination Plant Size (MGD)			
	0.2	1	3	10
	Concentrate Flow (MGD)			
Item	(0.03)	(0.14)	(0.4)	(1.4)
Required Land (acres)				
Evaporation Area (acres)	13	64	183	641
Total Land (acres)	19	79	216	733
Costs in 1,000s of Dollars	**($1,000)**	**($1,000)**	**($1,000)**	**($1,000)**
Capital Costs				
Evaporation Pond for Concentrate	$672	$ 2,864	$7,818	$26,498
Total Capital Cost	$672	$ 2,864	$7,818	$26,498
Engineering, Legal, and Contingencies	$236	$1,002	$2,737	$9,274
Environmental & Archaeology Studies and Mitigation	$132	$ 132	$189	$264
Land Acquisition and Surveying	$11	$ 65	$178	$604
Interest During Construction (2 years)	$85	$327	$879	$2,949
Total Project Cost	$1,137	$ 4,390	$11,801	$39,589
Annual Costs				
Debt Service (6 percent, 30 years)	$83	$ 318	$857	$2,874
Evaporation Pond Concentrate Disposal (O&M)	$10	$ 43	$117	$397
Total Annual Costs	$93	$ 362	$974	$3,273
Available Project Yield (acft/yr)	193	964	2,899	9,664
Annual Cost ($ per acft of Desalted Water)	$482	$376	$336	$339
Annual cost ($ per 1,000 gals of Desalted Water)	$1.48	$1.15	$1.03	$1.04

regression cost model developed by the U.S. Bureau of Reclamation[10] (USBR). The calculated evaporation area was increased by a scaling expression, as recommended by the USBR, to account for the perimeter area that includes access roadways, fencing, and the dike. Land acquisition and clearing costs were estimated to be $600 per acre and $500 per acre, respectively. To prevent leakage, design included the cost of a single 60 millimeter impervious liner.

For Evaporation Pond facilities to dispose of concentrates from desalination of brackish groundwater having 1,500 mg/L of TDS, total project costs (capital plus engineering, legal, contingencies, land acquisition, surveying and interest during construction) are $1,137,000 for a

Table 3.3-7.
Estimated Evaporation Pond Surface Area and Costs for Concentrate Disposal from RO Desalination of Brackish Groundwater of 3,000 mg/L of TDS for 0.2 MGD, 1 MGD, 3 MGD, and 10 MGD Sized Desalination Plants

	Desalination Plant Size (MGD)			
	0.2	1	3	10
	Concentrate Flow (MGD)			
Item	**0.04**	**0.21**	**0.64**	**2.12**
Required Land (acres)				
Evaporation Area (acres)	20	97	291	971
Total Land (acres)	28	120	344	1,110
Costs in 1,000s of Dollars	**($1,000)**	**($1,000)**	**($1,000)**	**($1,000)**
Capital Costs				
Evaporation Pond for Concentrate	$1,006	$4,340	$12,430	$40,128
Total Capital Cost	$1,006	$4,340	$12,430	$40,128
Engineering, Legal, and Contingencies	$352	$1,519	$4,351	$14,045
Environmental & Archaeology Studies and Mitigation	$200	$200	$300	$400
Land Acquisition and Surveying	$16	$99	$283	$914
Interest During Construction (2 years)	$127	$496	$1,398	$4,467
Total Project Cost	$1,701	$6,654	$18,762	$59,954
Annual Costs				
Debt Service (6 percent, 30 years)	$124	$483	$1,363	$4,353
Evaporation Pond Concentrate Disposal (O&M)	$15	$66	$187	$602
Total Annual Costs	$138	$549	$1,550	$4,955
Available Project Yield (acft/yr)	177	883	2,651	8,835
Annual Cost ($ per acft of Desalted Water)	$785	$622	$585	$561
Annual cost ($ per 1,000 gals of Desalted Water)	$2.41	$1.91	$1.79	$1.72

[10] Mickley, Michael C., 2001. Membrane Concentrate Disposal Practices and Regulation. Desalination and Water Purification Research and Development Program Report No. 69. U.S. Department of the Interior: Bureau of Reclamation.

0.2 MGD facility (Table 3.3-6). The 0.2 MGD facility would produce 193 acft of desalted water per year with a concentrate disposal cost of $482 per acft, or $1.48 per 1,000 gallons. Total project costs for a 3 MGD facility are $11,801,000, and for a 10 MGD facility are $39,589,000 (Table 3.3-6), with production of 2,899 and 9,664 acft/yr of water, respectively, at costs of $1.03 and $1.04 per1,000 gallons, respectively (Table 3.3-6).

For Evaporation Pond facilities to dispose of concentrates from desalination of brackish groundwater having 3,000 mg/L of TDS, total project costs (capital plus engineering, legal, contingencies, land acquisition, surveying and interest during construction) are $1,701,000 for a 0.2 MGD facility (Table 3.3-7). The 0.2 MGD facility would produce 177 acft of desalted water per year with a concentrate disposal cost of $785 per acft, or $2.41 per 1,000 gallons.

Table 3.3-8.
Estimated Evaporation Pond Surface Area and Costs for Concentrate Disposal from RO Desalination of Brackish Groundwater of 5,000 mg/L of TDS for 0.2 MGD, 1 MGD, 3 MGD, and 10 MGD Sized Desalination Plants

	Desalination Plant Size (MGD)			
	0.2	1	3	10
	Concentrate Flow (MGD)			
Item	**0.05**	**0.27**	**0.80**	**2.7**
Required Land (acres)				
Evaporation Area (acres)	25	124	366	1,237
Total Land (acres)	34	153	433	1,414
Costs in 1,000s of Dollars	**($1,000)**	**($1,000)**	**($1,000)**	**($1,000)**
Capital Costs				
Evaporation Pond for Concentrate	$1,260	$5,550	$15,635	$51,114
Total Capital Cost	$1,260	$5,550	$15,635	$51,114
Engineering, Legal, and Contingencies	$441	$1,942	$5,473	$17,890
Environmental & Archaeology Studies and Mitigation	$200	$255	$377	$509
Land Acquisition and Surveying (120 acres)	$21	$126	$355	$1,164
Interest During Construction (2 years)	$155	$634	$1,758	$5,689
Total Project Cost	$2,077	$8,510	$23,601	$76,368
Annual Costs				
Debt Service (6 percent, 30 years)	$151	$617	$1,714	$5,548
Evaporation Pond Concentrate Disposal (O&M)	$19	$84	$235	$766
Total Annual Costs	$170	$702	$1,948	$6,311
Available Project Yield (acft/yr)	164	818	2,446	8,153
Annual Cost ($ per acft of Desalted Water)	$1,037	$858	$797	$774
Annual cost ($ per 1,000 gals of Desalted Water)	$3.18	$2.63	$2.44	$2.38

Total project costs for a 3 MGD facility are $18,762,000, and for a 10 MGD facility are $59,954,000 (Table 3.3-7), with production of 2,651 and 8,835 acft/yr of water, respectively, at costs of $1.79 and $1.72 per 1,000 gallons, respectively (Table 3.3-7).

For Evaporation Pond facilities to dispose of concentrates from desalination of brackish groundwater having 5,000 mg/L of TDS, total project costs (capital plus engineering, legal, contingencies, land acquisition, surveying and interest during construction) are $2,077,000 for a 0.2 MGD facility (Table 3.3-8). The 0.2 MGD facility would produce 164 acft of desalted water per year with a concentrate disposal cost of $1,037 per acft, or $3.18 per 1,000 gallons. Total project costs for a 3 MGD facility are $23,601,000, and for a 10 MGD facility are

Table 3.3-9.
Estimated Evaporation Pond Surface Area and Costs for Concentrate Disposal from RO Desalination of Brackish Groundwater of 20,000 mg/L of TDS for 0.2 MGD, 1 MGD, 3 MGD, and 10 MGD Sized Desalination Plants

Item	Desalination Plant Size (MGD)			
	0.2	0.40	1.2	4.0
	Concentrate Flow (MGD)			
	0.08	0.40	1.2	4.0
Required Land (acres)				
Evaporation Area (acres)	37	184	549	1,832
Total Land (acres)	49	227	649	2,095
Costs in 1,000s of Dollars	**($1,000)**	**($1,000)**	**($1,000)**	**($1,000)**
Capital Costs				
Evaporation Pond for Concentrate	$1,770	$8,222	$23,453	$75,724
Total Capital Cost	$1,770	$8,222	$23,453	$75,724
Engineering, Legal, and Contingencies	$620	$2,878	$8,209	$26,504
Environmental & Archaeology Studies and Mitigation	$200	$378	$566	$754
Land Acquisition and Surveying (153 acres)	$30	$187	$533	$1,724
Interest during Construction (2 years)	$211	$939	$2,637	$8,429
Total Project Cost	$2,831	$12,607	$35,402	$113,138
Annual Costs				
Debt Service (6 percent, 30 years)	$206	$915	$2,570	$8,213
Evaporation Pond Concentrate Disposal (O&M)	$27	$125	$352	$1,136
Total Annual Costs	$233	$1,040	$2,923	$9,349
Available Project Yield (acft/yr)	135	673	2,018	6,726
Annual Cost ($ per acft of Desalted Water)	$1,726	$1,548	$1,448	$1,390
Annual Costs ($ per 1,000 gals of Desalted Water)	$5.30	$4.75	$4.45	$4.27

$76,368,000 (Table 3.3-8), with production of 2,446 and 8,153 acft/yr of water, respectively, at costs of $2.44 and $2.38 per 1,000 gallons, respectively (Table 3.3-8).

For Evaporation Pond facilities to dispose of concentrates from desalination of brackish groundwater having 20,000 mg/L of TDS, total project costs (capital plus engineering, legal, contingencies, land acquisition, surveying and interest during construction) are $2,831,000 for a 0.2 MGD facility (Table 3.3-9). The 0.2 MGD facility would produce 135 acft of desalted water per year with a concentrate disposal cost of $1,726 per acft, or $5.30 per 1,000 gallons. Total project costs for a 3 MGD facility are $35,402,000, and for a 10 MGD facility are $113,138,000 (Table 3.3-9), with production of 2,018 and 6,726 acft/yr of water, respectively, at costs of $4.45 and $4.27 per 1,000 gallons, respectively (Table 3.3-9).

3.3.2.2 Deep Well Injection—Method and Costs

Deep well injection is a specialized disposal technique whereby liquid wastes (e.g., municipal wastes, hazardous wastes, and produced waters from oil field operations) are pumped into the deep subsurface. Injection wells have been used to dispose of wastes for many years in Gulf Coast states such as Florida, Louisiana, and Texas. These wells, called Class I wells, commonly extend 1,000 to 8,000 feet into the subsurface to isolate the wastes from the environment and prevent contamination of potable groundwater sources. It is crucial, therefore, that the contiguous geologic formations prevent the migration of wastes out of the injection zone.

Selection of a suitable injection site depends primarily on geologic and hydrogeologic conditions. The well must be located and completed in a porous subsurface formation that is beneath the lowermost source of fresh water and separated from that source by a layer of impermeable strata. Findings of a study performed for the Texas Water Development Board conclude that the geologic formations in the study area are amenable to concentrate injection.[11] Furthermore, this study indicates that opportunities may exist to dispose of the concentrate in existing oil and gas wells (Class II wells). Current TCEQ guidance allows desalination concentrate to be injected into existing Class II wells if the desalination concentrate is being injected for the active recovery of oil and/or gas from a producing well field. Therefore, use of an existing Class II well for desalination concentrate disposal may not be a dependable long-term

[11] Bureau of Economic Geology, 2004. Please Pass the Salt: Using Oil Fields for the Disposal of Concentrate from Desalination Plants. Prepared for Texas Water Development Board.

disposal option because it is dependant on the continued use of the well for oil and/or gas production. Alternatively, it may be possible to convert a Class II well to a Class I disposal well. However, the permitting process to convert a Class II well to a Class I disposal well can be a hindrance to small desalination facilities due to the requirements of the application process. Underground Injection Control regulations of the U.S. Environmental Protection Agency require an Area of Review (AOR) study be performed in the conversion of Class II wells, but a variance of AOR request can be granted by demonstrating any of the following evidence:

- Reservoir pressure is insufficient to raise injection fluids to groundwater;
- Geological conditions preclude upward movement of fluids;
- Aquifers with water of good quality (less than 10,000 mg/L TDS) are absent in the injection area;
- Lack of intersection (i.e., no adjacent well is drilled to the depth of the injection zone); and
- Mitigating geological factors (e.g., 100 ft of continuous impervious strata).

Design and construction of a deep injection well requires knowledge of the concentrate flow rate and site-specific conditions. New injection wells are constructed in successive stages of drilling, casing, and cementing to the target well depth. The concentrate injection tube is commonly oversized to accommodate potential future increases in concentrate flow, however, details related to installation strategies and techniques vary widely depending on site-specific geological conditions and, therefore, cannot e specified until specific sites are selected. Therefore, cost estimates presented below are for more or less “generic” sites, and may be different if individual sites have specific needs or problems.

Tables 3.3-10 through 3.3-13 show the hydraulic provisions and associated costs for deep injection wells to dispose of concentrate from desalination facilities treating groundwater with flows and qualities that are summarized in Table 3.3-1. Costs were estimated using a regression model developed by the USBR and assume the construction of new wells extending to a depth of 5,000 feet. The estimates assume hydrological conditions in the project area would allow for construction of wells with an injection flow rate up to 500 gpm. Therefore, for the concentrate from a groundwater with 1,500 mg/l of TDS, one injection well is estimated for the 0.03 MGD, 0.14 MGD and 0.4 MGD concentrate flow rates for the 0.2 MGD, 1 MGD and the 3 MGD desalt plants, respectively (Table 3-10). It is estimated that two injection wells will be needed for the 1.4 MGD concentrate flow rate from a 10 MGD desalination plant (Table 3-10). The costs represent an order of magnitude estimate; a site-specific evaluation must be conducted to provide a more accurate estimate given the intrinsic uncertainty associated with the siting and construction of deep injection wells.

For Deep Well Injection facilities to dispose of concentrates from desalination of brackish groundwater having 1,500 mg/L of TDS, total project costs (capital plus engineering, legal, contingencies, land acquisition, surveying and interest during construction) are $7,452,000 for a 0.2 MGD facility (Table 3.3-10). The 0.2 MGD facility would produce 193 acft of desalted water per year with a concentrate disposal cost of $3,176 per acft, or $9.75 per 1,000

Table 3.3-10.
Estimated Hydraulic Conditions and Costs for Deep Well Injection of Concentrate from RO Desalination of Brackish Groundwater of 1,500 mg/L of TDS for 0.2 MGD, 1 MGD, 3 MGD, and 10 MGD Sized Desalination Plants

Item	Desalination Plant Size (MGD)			
	0.2	1	3	10
	Concentrate Flow (MGD)			
	0.03	0.14	0.4	1.4
Number of Injection Wells	1	1	1	2
Hydraulic Conditions				
Tubing Diameter (inches)	2	3	4	6
Injection Velocity (feet/second)	1.9	4.4	7.1	5.5
Costs in 1,000s of Dollars	**($1,000)**	**($1,000)**	**($1,000)**	**($1,000)**
Capital Costs				
Deep Wells for Concentrate Injection	$4,800	$5,000	$5,185	$11,115
Total Capital Costs	$4,800	$5,000	$5,185	$11,115
Engineering, Legal, and Contingencies	$1,680	$1,750	$1,815	$3,890
Environmental & Archaeology Studies and Mitigation	$410	$410	$510	$620
Land Acquisition and Surveying (0 acres)	$10	$10	$10	$20
Interest During Construction (2 years)	$552	$574	$602	$1,252
Total Project Cost	$7,452	$7,744	$8,122	$16,897
Annual Costs				
Debt Service (6 percent, 30 years)	$541	$563	$590	$1,228
Deep Well Injection (O&M)	$72	$75	$78	$ 167
Total Annual Costs	$613	$638	$668	$1,395
Available Project Yield (acft/yr)	193	964	2,899	9,664
Annual Cost ($ per acft of Desalted Water)	$3,176	$662	$230	$144
Annual cost ($ per 1,000 gals of Desalted Water)	$9.75	$2.03	$0.71	$0.44

gallons. Total project costs for a 3 MGD facility are $8,122,000, and for a 10 MGD facility are $16,897,000 (Table 3.3-10), with production of 2,899 and 9,664 acft/yr of water, respectively, at costs of $0.71 and $0.44 per 1,000 gallons, respectively (Table 3.3-10).

For Deep Well Injection facilities to dispose of concentrates from desalination of brackish groundwater having 3,000 mg/L of TDS, total project costs (capital plus engineering, legal, contingencies, land acquisition, surveying and interest during construction) are $7,452,000 for a 0.2 MGD facility (Table 3.3-11). The 0.2 MGD facility would produce 177 acft of desalted water per year with a concentrate disposal cost of $3,463 per acft, or $10.63 per 1,000

Table 3.3-11.
Estimated Hydraulic Conditions and Costs for Deep Well Injection of Concentrate from RO Desalination of Brackish Groundwater of 3,000 mg/L of TDS for 0.2 MGD, 1 MGD, 3 MGD, and 10 MGD Sized Desalination Plants

Item	Desalination Plant Size (MGD)			
	0.2	1	3	10
	Concentrate Flow (MGD)			
	0.04	0.21	0.64	2.12
Number of Injection Wells	1	1	1	3
Hydraulic Conditions				
Tubing Diameter (inches)	2	3	6	6
Injection Velocity (feet/second)	3.0	6.7	5	5.6
Costs in 1,000s of Dollars	**($1,000)**	**($1,000)**	**($1,000)**	**($1,000)**
Capital Costs				
Deep Wells for Concentrate Injection	$4,800	$5,000	$5,558	$13,072
Total Capital Costs	$4,800	$5,000	$5,558	$13,072
Engineering, Legal, and Contingencies	$1,680	$1,750	$1,945	$4,575
Environmental & Archaeology Studies and Mitigation	$410	$410	$510	$730
Land Acquisition and Surveying (0 acres)	$10	$10	$10	$30
Interest During Construction (2 years)	$552	$574	$642	$1,473
Total Project Cost	$7,452	$7,744	$8,665	$19,880
Annual Costs				
Debt Service (6 percent, 30 years)	$541	$563	$630	$1,444
(O&M)	$72	$75	$84	$250
Total Annual Costs	$613	$638	$714	$1,694
Available Project Yield (acft/yr)	177	883	2,651	8,835
Annual Cost ($ per acft of Desalted Water)	$3,463	$723	$269	$192
Annual cost ($ per 1,000 gals of Desalted Water)	$10.63	$2.22	$0.83	$0.59

gallons. Total project costs for a 3 MGD facility are $8,665,000, and for a 10 MGD facility are $19,880,000 (Table 3.3-11), with production of 2,651 and 8,835 acft/yr of water, respectively, at costs of $0.83 and $0.59 per 1,000 gallons, respectively (Table 3.3-11).

For Deep Well Injection facilities to dispose of concentrates from desalination of brackish groundwater having 5,000 mg/L of TDS, total project costs (capital plus engineering, legal, contingencies, land acquisition, surveying and interest during construction) are $7,542,000 for a 0.2 MGD facility (Table 3.3-12). The 0.2 MGD facility would produce 164 acft of desalted water per year with a concentrate disposal cost of $3,738 per acft, or $11.47 per 1,000 gallons.

Table 3.3-12.
Estimated Hydraulic Conditions and Costs for Deep Well Injection of Concentrate from RO Desalination of Brackish Groundwater of 5,000 mg/L of TDS for 0.2 MGD, 1 MGD, 3 MGD, and 10 MGD Sized Desalination Plants

Item	Desalination Plant Size (MGD)			
	0.2	1	3	10
	Concentrate Flow (MGD)			
	0.05	0.27	0.8	2.7
Number of Injection Wells	1	1	2	4
Hydraulic Conditions				
Tubing Diameter (inches)	2	4	4	6
Injection Velocity (feet/second)	3.9	4.8	7.2	5.4
Costs in 1,000s of Dollars	**($1,000)**	**($1,000)**	**($1,000)**	**($1,000)**
Capital Costs				
Deep Wells for Concentrate Injection	$4,800	$5,185	$10,370	$22,230
Total Capital Costs	$4,800	$5,185	$10,370	$22,230
Engineering, Legal, and Contingencies	$1,680	$1,815	$3,630	$7,781
Environmental & Archaeology Studies and Mitigation	$410	$410	$620	$840
Land Acquisition and Surveying (0 acres)	$10	$10	$20	$40
Interest During Construction (2 years)	$552	$594	$1,172	$2,472
Total Project Cost	$7,452	$8,014	$15,812	$33,363
Annual Costs				
Debt Service (6 percent, 30 years)	$541	$582	$1,149	$2,424
(O&M)	$72	$78	$156	$333
Total Annual Costs	$613	$660	$1,305	$2,757
Available Project Yield (acft/yr)	164	818	2,446	8,153
Annual Cost ($ per acft of Desalted Water)	$3,738	$807	$534	$338
Annual cost ($ per 1,000 gals of Desalted Water)	$11.47	$2.48	$1.64	$1.04

Total project costs for a 3 MGD facility are $15,812,000, and for a 10 MGD facility are $33,363,000 (Table 3.3-12), with production of 2,446 and 8,153 acft/yr of water, respectively, at costs of $1.64 and $1.04 per 1,000 gallons, respectively (Table 3.3-12).

For Deep Well Injection facilities to dispose of concentrates from desalination of brackish groundwater having 20,000 mg/L of TDS, total project costs (capital plus engineering, legal, contingencies, land acquisition, surveying and interest during construction) are $7,468,000 for a 0.2 MGD facility (Table 3.3-13). The 0.2 MGD facility would produce 135 acft of desalted water per year with a concentrate disposal cost of $4,556 per acft, or $13.98 per 1,000 gallons.

Table 3.3-13.
Estimated Hydraulic Conditions and Costs for Deep Well Injection of Concentrate from RO Desalination of Brackish Groundwater of 20,000 mg/L of TDS for 0.2 MGD, 1 MGD, 3 MGD, and 10 MGD Sized Desalination Plants

Item	Desalination Plant Size (MGD)			
	0.2	1	3	10
	Concentrate Flow (MGD)			
	0.08	0.4	1.2	4.0
Number of Injection Wells	1	1	2	6
Hydraulic Conditions				
Tubing Diameter (inches)	2	4	6	6
Injection Velocity (feet/second)	5.7	7.1	4.7	5.3
Costs in 1,000s of Dollars	**($1,000)**	**($1,000)**	**($1,000)**	**($1,000)**
Capital Costs				
Deep Wells for Concentrate Injection	$4,810	$5,185	$11,115	$33,345
Total Capital Costs	$4,810	$5,185	$11,115	$33,345
Engineering, Legal, and Contingencies	$1,684	$1,815	$3,890	$11,671
Environmental & Archaeology Studies and Mitigation	$410	$410	$620	$1,060
Land Acquisition and Surveying (0 acres)	$10	$10	$20	$60
Interest During Construction (2 years)	$554	$594	$1,252	$3,691
Total Project Cost	$7,468	$8,014	$16,897	$49,827
Annual Costs				
Debt Service (6 percent, 30 years)	$543	$582	$1,228	$3,620
(O&M)	$72	$78	$167	$500
Total Annual Costs	$615	$660	$1,395	$4,120
Available Project Yield (acft/yr)	135	673	2,018	6,726
Annual Cost ($ per acft of Desalted Water)	$4,556	$981	$691	$613
Annual cost ($ per 1,000 gals of Desalted Water)	$13.98	$3.01	$2.12	$1.88

Total project costs for a 3 MGD facility are $16,897,000, and for a 10 MGD facility are $49,827,540 (Table 3.3-13), with production of 2,018 and 6,726 acft/yr of water, respectively, at costs of 2.12 and $1.88 per 1,000 gallons, respectively (Table 3.3-13).

3.3.3 Cost Estimates for Desalted Water Supply

Tables 3.3-14 through 3.3-17 summarize the estimated costs of the desalted water supply, including the raw water well field, brackish groundwater desalination water treatment plant, and concentrate disposal. The raw water well field costs for groundwater supplies with TDS of 1,500 to 5,000 mg/l are from the Deaf Smith well field presented in Section 3.2. For the higher TDS groundwater supply with TDS of 20,000 mg/l the raw water well field cost is from the Parmer-Castro-Lamb well field presented in Section 3.2.

Desalted water supply costs for Dockum Aquifer water with 1,500 mg/l of TDS are summarized in Table 3.3-14 for brackish groundwater RO desalination facility sizes of 0.2 MGD, 1 MGD, 3 MGD, and 10 MGD, respectively. The desalination process flow estimates in Table 3.3-1 for a groundwater with 1,500 mg/l of TDS are utilized for the Dockum Aquifer brackish groundwater cost estimates. The estimated concentrate disposal cost for the 0.2 MGD and 1 MGD sized facility is based upon solar evaporation ponds concentrate disposal, and on deep well injection concentrate disposal for the RO desalination facility sizes of 3 MGD and 10

Table 3-14.
Cost Estimate Summary for RO Desalination of 1,500 mg/L Brackish Groundwater from the Dockum Aquifer for 0.2 MGD, 1 MGD, 3 MGD, and 10 MGD Raw Water Supplies – Deaf Smith County

Item	Desalination Plant Size (MGD)			
	0.2	1	3	10
Annual Project Yield (acft/yr) from Table 3.3-2	**193**	**964**	**2,899**	**9,664**
Raw (Brackish) Water Cost				
Deaf Smith County ($ per acft) from Table 3.2-2	438	365	305	314
Desalination Cost ($ acft/yr) from Table 3.3-2	825	484	362	287
Concentrate Disposal Cost ($ per acft) from Tables 3.3-6 &10	482	376	230	144
Total Cost (Raw Water, Desalination, Concentrate Disposal)				
Deaf Smith County ($ per acft)	1,745	1,225	897	745
Deaf Smith County ($ per 1,000 gallons)	5.35	3.76	2.75	2.29

MGD. The cost summary includes costs for raw water, desalination, and concentrate disposal (Table 3.3-14). For a Deaf Smith County Dockum Aquifer well field location, cost per acft is estimated at $1,745 ($5.35 per 1,000 gallons) for a 0.2 MGD desalination facility, $1,225 ($3.76 per 1,000 gallons) for a 1 MGD desalination facility, $897 per acft ($2.75 per 1,000 gallons) for a 3 MGD facility, and $745 per acft ($2.29 per 1,000 gallons) for a 10 MGD sized facility (Table 3.3-14).

Desalinated water supply costs for Dockum Aquifer water with 3,000 mg/l of TDS are summarized in Table 3-15 for brackish groundwater RO desalination facility sizes of 0.2 MGD, 1 MGD, 3 MGD, and 10 MGD, respectively. The desalination process flow estimates in Table 3-1 for a groundwater with 3,000 mg/l of TDS are utilized for the Dockum Aquifer brackish groundwater cost estimates. The estimated concentrate disposal cost for the 0.2 MGD and 1 MGD sized facility is based upon solar evaporation ponds concentrate disposal, and are based on deep well injection concentrate disposal for the RO desalination facility sizes of 3 MGD and 10 MGD. The cost summary includes costs for raw water, desalination, and concentrate disposal (Table 3.3-15). For a Deaf Smith County Dockum Aquifer well field location, cost per acft is estimated at $2,169 ($6.66 per 1,000 gallons) for a 0.2 MGD Desalination facility, $1,554 ($4.77 per 1,000 gallons) for a 1 MGD Desalination facility, $1,000 per acft ($3.07 per 1,000 gallons)

Table 3.3-15.
Cost Estimate Summary for RO Desalination of 3,000 mg/L Brackish Groundwater from the Dockum Aquifer for 0.2 MGD, 1 MGD, 3 MGD, and 10 MGD Sized Desalination Plants – Deaf Smith County

Item	Desalination Plant Size (MGD)			
	0.2	1	3	10
Annual Project Yield (acft/yr) from Table 3.3-3	**177**	**883**	**2,651**	**8,835**
Raw (Brackish) Water Cost				
Deaf Smith County ($ per acft) from Table 3.2-2	438	365	305	314
Desalination Cost ($ acft/yr) from Table 3.3-3	946	567	426	345
Concentrate Disposal Cost ($ per acft) from Tables 3.3-7 & 11	785	622	269	192
Total Cost (Raw Water, Desalination, Concentrate Disposal)				
Deaf Smith County ($ per acft)	2,169	1,554	1,000	851
Deaf Smith County ($ per 1,000 gallons)	6.66	4.77	3.07	2.61

for a 3 MGD facility, and $851 per acft ($2.61 per 1,000 gallons) for a 10 MGD sized facility (Table 3.3-15).

Desalinated water supply costs for Dockum Aquifer water with 5,000 mg/l of TDS are summarized in Table 3.3-16 for brackish groundwater RO desalination facility sizes of 0.2 MGD, 1 MGD, 3 MGD, and 10 MGD, respectively. The desalination process flow estimates in Table 3.3-1 for a groundwater with 5,000 mg/l of TDS are utilized for the Dockum Aquifer brackish groundwater cost estimates. The estimated concentrate disposal costs are based on deep well injection concentrate disposal for the RO desalination facility sizes of 0.2 MGD, 1 MGD, 3 MGD and 10 MGD, since this is the method with the lower estimated cost. The cost summary includes costs for raw water, desalination, and concentrate disposal (Table 3.3-16). For a Deaf Smith County Dockum Aquifer well field location, cost per acft is estimated at $2,587 ($7.94 per 1,000 gallons) for a 0.2 MGD Desalination facility, $1,815 ($5.57 per 1,000 gallons) for a 1 MGD Desalination facility, $1,330 per acft ($4.08 per 1,000 gallons) for a 3 MGD facility, and $1,052 per acft ($3.23 per 1,000 gallons) for a 10 MGD sized facility (Table 3.3-16).

Table 3.3-16.
Cost Estimate Summary for RO Desalination of 5,000 mg/L Brackish Groundwater from the Dockum Aquifer for 0.2 MGD, 1 MGD, 3 MGD, and 10 MGD Sized Desalination Plants – Deaf Smith County

Item	Desalination Plant Size (MGD			
	0.2	1	3	10
Annual Project Yield (acft/yr) from Table 3.3-4	**164**	**818**	**2,446**	**8,153**
Raw (Brackish) Water Cost				
Deaf Smith County ($ per acft) from Table 3.2-2	438	365	305	314
Desalination Cost ($ acft/yr) from Table 3.3-4	1,112	643	491	400
Concentrate Disposal Cost ($ per acft) from Table 3.3-12	1,037	807	534	338
Total Cost (Raw Water, Desalination, Concentrate Disposal)				
Deaf Smith County ($ per acft)	2,587	1,815	1,330	1,052
Deaf Smith County ($ per 1,000 gallons)	7.94	5.57	4.08	3.23

Desalinated water supply costs for Dockum Aquifer water with 20,000 mg/l of TDS are summarized in Table 3.3-17 for brackish groundwater RO desalination facility sizes of 0.2 MGD, 1 MGD, 3 MGD, and 10 MGD, respectively. The desalination process flow estimates in Table 3.3-1 for a groundwater with 20,000 mg/l of TDS are utilized for the Dockum Aquifer brackish groundwater cost estimates. The estimated concentrate disposal costs are based on deep well injection concentrate disposal for the RO desalination facility sizes of 0.2 MGD, 1 MGD, 3 MGD and 10 MGD, since this is the method with the lower estimated cost. The cost summary includes costs for raw water, desalination, and concentrate disposal (Table 3.3-17). For a Castro-Lamb-Parmer County line Dockum Aquifer well field location, cost per acft is estimated at $3,727 ($11.44 per 1,000 gallons) for a 0.2 MGD Desalination facility, $2,349 ($7.21 per 1,000 gallons) for a 1 MGD Desalination facility, $1,829 per acft ($5.62 per 1,000 gallons) for a 3 MGD facility, and $1,660 per acft ($5.10 per 1,000 gallons) for a 10 MGD sized facility (Table 3.3-17).

Table 3.3-17.
Cost Estimate Summary for RO Desalination of 20,000 mg/L Brackish Groundwater from the Dockum Aquifer for 0.2 MGD, 1 MGD, 3 MGD, and 10 MGD Sized Desalination Plants – Parmer-Castro-Lamb Counties

Item	Desalination Plant Size (MGD			
	0.2	1	3	10
Annual Project Yield (acft/yr) from Table 3.3-5	**135**	**673**	**2,018**	**6,726**
Raw (Brackish) Water Cost				
Castro-Lamb-Parmer Counties ($ per acft) from Table 3.2-2	455	464	441	476
Desalination Cost ($ acft/yr) from Table .33-5	1,546	904	697	571
Concentrate Disposal Cost ($ per acft) from Table 3.3-13	1,726	981	691	613
Total Cost (Raw Water, Desalination, Concentrate Disposal)				
Deaf Smith County ($ per acft)	3,727	2,349	1,829	1,660
Deaf Smith County ($ per 1,000 gallons)	11.44	7.21	5.62	5.10

3.3.4 Estimated Environmental Effects of Water Management Strategies using Dockum Aquifer Water

The importance or magnitude of particular regulatory programs and environmental issues depends on the site specific characteristics of the project footprint and the operational characteristics of the facility. The development of this facility and the related regulatory and environmental considerations can be subdivided into three primary efforts that relate to the major design and construction tasks: (1) development of the well field, (2) construction of the treatment facility, and (3) disposal of concentrate.

New wells in the Dockum Aquifer are not expected to have a substantial impact on the surrounding aquifer. However, studies should be conducted to examine any potential effect on the quality and water level of the aquifer and assess any potential impacts to surrounding wells and the base flow of nearby surface water.

Depending on the location of the treatment facility, habitat studies and environmental surveys may be needed to avoid or reduce the impact to protected species or sensitive habitat. Cultural, historical, and archeological studies may also be necessary. Though an alignment for the finished water delivery pipeline has not been selected at this time, similar studies will likely be needed when evaluating candidate pipeline routes.

Disposal of concentrate presents the most considerable regulatory and environmental challenges because desalination concentrate is presently classified as an industrial waste. As a result, evaluation of the concentrate disposal system is presented separately in the previous section.

In addition to these environmental considerations, ultimate implementation of the proposed brackish groundwater desalination strategy requires consideration of the ensuing issues:

- Verification of available groundwater water quantities and well productivity for the Dockum Aquifer in Bailey, Castro, Deaf Smith, Hale, and Parmer Counties;
- Verification of Dockum Aquifer water quality for both concentrations of the dissolved constituents (e.g., TDS and chloride) and particles that would require additional pretreatment (e.g., iron and manganese);
- Compliance with TCEQ regulatory mandates;
- Verification that the desalinated Dockum Aquifer water is compatible with other water sources and will meet all water quality requirements in the end user's distribution system;
- Coordination with appropriate federal, state, and local agencies to obtain permits and approvals that may be required in the design and construction of the facility; and
- Experience in the operation and maintenance of a desalination water treatment plant.

3.3.5 Summary of Estimated Costs to Obtain and Desalt Water from the Dockum Aquifer in Deaf Smith, Castro, Lamb, and Parmer Counties

Costs were estimated for desalination using Reverse Osmosis (RO) and concentrate disposal using solar evaporation and deep well injection for 0.2 MGD, 1 MGD, 3 MGD, and 10 MGD sized Dockum Aquifer well fields having 1,500, 3,000, 5,000, and 20,000 mg/L

Table 3.3-18.
Cost Estimate Summary for RO Desalination of Brackish Groundwater from the Dockum Aquifer for 0.2 MGD, 1 MGD, 3 MGD,and 10 MGD Sized Desalination Plants -- Deaf Smith, and Parmer-Castro-Lamb Counties

Desalt Plant Size	Raw Water Total Dissolved Solids (mg/L)							
	1,500		3,000		5,000		20,000	
	Yield/acft	Cost/acft	Yield/acft	Cost/acft	Yield/acft	Cost/acft	Yield/acft	Cost/acft
Deaf Smith Location -- Raw Water (Table 3.2-2)								
0.2 MGD	224	438	224	438	224	438	NA	NA
1 MGD	1,120	365	1,120	365	1,120	365	NA	NA
3 MGD	3,360	305	3,360	305	3,360	305	NA	NA
10 MGD	11,200	314	11,200	314	11,200	314	NA	NA
Parmer-Castro-Lamb Location -- Raw Water (Table 3.2-2)								
0.2 MGD	NA	NA	NA	NA	NA	NA	224	455
1 MGD	NA	NA	NA	NA	NA	NA	1,120	464
3 MGD	NA	NA	NA	NA	NA	NA	3,360	441
10 MGD	NA	NA	NA	NA	NA	NA	11,200	476
Desalination Costs (Tables 3.3-2, 3.3-3, 3.3-4, and 3.3-5)								
0.2 MGD	193	825	177	946	164	1,112	135	1,546
1 MGD	964	484	883	567	818	643	673	903
3 MGD	2,899	362	2,651	426	2,446	491	2,018	697
10 MGD	9,664	287	8,835	345	8,153	400	6,726	571
Solar Pond Concentrate Disposal Costs (Tables 3.3-6, 3.3-7, 3.3-8, and 3.3-9)								
0.2 MGD	193	482	177	785	164	1,037	135	1,726
1 MGD	964	376	883	622	818	858	673	1,548
3 MGD	2,899	336	2,651	585	2,446	797	2,018	1,448
10 MGD	9,664	339	8,835	561	8,153	774	6,726	1,390
Deep Well Concentrate Disposal Costs (Tables 3.3-10, 3.3-11, 3.3-12, and 3.3-13)								
0.2 MGD	193	3,176	177	3,463	164	3,738	135	4,556
1 MGD	964	662	883	723	818	807	673	981
3 MGD	2,899	230	2,651	269	2,446	534	2,018	691
10 MGD	9,664	144	8,835	192	8,153	338	6,726	613
Total Costs (Raw Water + Desalt + Lowest Cost Concentrate Disposal) ($/acft) (Tables 3-14 & 3-17)								
0.2 MGD	193	1,745	177	2,169	164	2,587	135	3,727
1 MGD	964	1,225	883	1,554	818	1,815	673	2,349
3 MGD	2,899	897	2,651	1,000	2,446	1,330	2,018	1,829
10 MGD	9,664	745	8,835	851	8,153	1,052	6,726	1,660
Total Costs ($/1,000 gal) (Raw Water + Desalt + Lowest Cost Concentrate Disposal) (Tables 3-14 & 3-17)								
0.2 MGD	193	5.35	177	6.65	164	7.94	135	11.44
1 MGD	964	3.76	883	4.77	818	5.57	673	7.21
3 MGD	2,899	2.75	2,651	3.07	2,446	4.08	2,018	5.62
10 MGD	9,664	2.29	8,835	2.61	8,153	3.23	6,726	5.10
								<><><>

concentrations of TDS. The costs of raw water at the well fields, desalination, concentrate disposal, and the sum of these costs are summarized below.

Raw Water at the Well Fields: Costs of raw water at a well field located in Deaf Smith County were estimated at $438 per acre-foot for a 0.2 MGD sized well field, $365 per acre-foot for a 1 MGD sized well field, $305 per acre-foot for a 3 MGD sized field, and $314 per acre-foot for a 10 MGD sized field (Table 3.3-18). The Dockum Aquifer in Deaf Smith County is estimated to produce water in the range of 1,500 mg/l to 5,000 mg/L. However, in a second well field near the Castro-Lamb-Parmer County lines, Dockum Aquifer water is estimated to be in the 20,000 mg/L range of TDS. Costs of raw water for a well field along the Castro-Lamb-Parmer County lines were estimated at $455 per acre-foot for a 0.2 MGD well field, $464 per acre-foot for a 1 MGD well field, $441 per acre-foot for a 3 MGD field, and $476 for a 10 MGD field (Table 3.3-18).

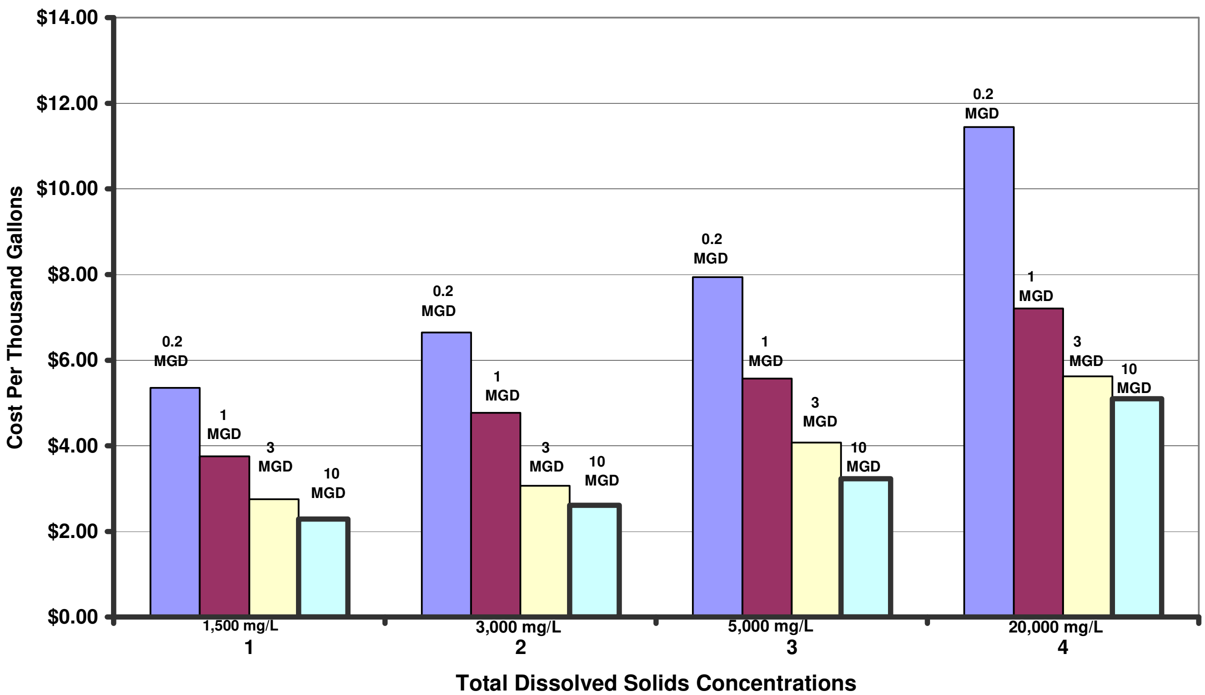
Desalination Costs: Estimated desalination costs for water with 1,500 mg/L range from $825 per acre-foot for a 0.2 MGD facility, to $484 per acre-foot for a 1 MGD facility, to $362 per acre-foot for a 3 MGD facility, and $287 per acre-foot for a 10 MGD facility (Table 3.3-18). Estimated desalination costs for water with 3,000 mg/L range from $ 946 per acre-foot for a 0.2 MGD facility, to $567 per acre-foot for a 1 MGD facility, to $426 per acre-foot for a 3 MGD facility, and $345 per acre-foot for a 10 MGD facility. Estimated desalination costs for water with 5,000 mg/L range from $1,112 per acre-foot for a 0.2 MGD facility, to $643 per acre-foot for a 1 MGD facility, to $491 per acre-foot for a 3 MGD facility, and $400 per acre-foot for a 10 MGD facility. Estimated desalination costs for water with 20,000 mg/L range from $1,546 per acre-foot for a 0.2 MGD facility, to $903 per acre-foot for a 1 MGD facility, to $697 per acre-foot for a 3 MGD facility, and $571 per acre-foot for a 10 MGD facility (Table 3.3-18).

Concentrate Disposal Using Solar Evaporation Ponds: Estimated concentrate disposal costs using solar evaporation for water with 1,500 mg/L range from $482 per acre-foot for a 0.2 MGD facility, to $376 per acre-foot for a 1 MGD facility, to $336 per acre-foot for a 3 MGD facility, and $339 per acre-foot for a 10 MGD facility (Table 3.3-18). Estimated concentrate disposal costs using solar evaporation for water with 3,000 mg/L range from $785 per acre-foot for a 0.2 MGD facility, to $622 per acre-foot for a 1 MGD facility, to $585 per acre-foot for a 3 MGD facility, and $561 per acre-foot for a 10 MGD facility. Estimated concentrate disposal costs using solar evaporation for water with 5,000 mg/L range from $1,037 per acre-foot for a

0.2 MGD facility, to $858 per acre-foot for a 1 MGD facility, to $797 per acre-foot for a 3 MGD facility, and $774 per acre-foot for a 10 MGD facility. Estimated concentrate disposal costs using solar evaporation for water with 20,000 mg/L range from $1,726 per acre-foot for a 0.2 MGD facility, to $1,548 per acre-foot for a 1 MGD facility, to $1,448 per acre-foot for a 3 MGD facility, and $1,301 per acre-foot for a 10 MGD facility (Table 3.3-18).

Concentrate Disposal Using Deep Well Injection: Estimated concentrate disposal costs using deep well injection for water with 1,500 mg/L range from $3,176 per acre-foot for a 0.2 MGD facility, to $662 per acre-foot for a 1 MGD facility, to $230 per acre-foot for a 3 MGD facility, and $144 per acre-foot for a 10 MGD facility (Table 3.3-18). Estimated concentrate

Figure 3.3-1: Costs of Desalted Dockum Aquifer Water Per 1,000 Gallons (Raw Water + Desalination + Concentrate Disposal)



disposal costs using deep well injection for water with 3,000 mg/L range from $3,463 per acre-foot for a 0.2 MGD facility, to $723 per acre-foot for a 1 MGD facility, to $269 per acre-foot for a 3 MGD facility, and $192 per acre-foot for a 10 MGD facility. Estimated concentrate disposal costs using deep well injection for water with 5,000 mg/L range from $3,738 per acre-foot for a 0.2 MGD facility, to $807 per acre-foot for a 1 MGD facility, to $534 per acre-foot for a 3 MGD facility, and $338 per acre-foot for a 10 MGD facility. Estimated concentrate disposal costs using deep well injection for water with 20,000 mg/L range from $4,556 per acre-foot for a 0.2 MGD facility, to $981 per acre-foot for a 1 MGD facility, to $691 per acre-foot for a 3 MGD facility, and $613 per acre-foot for a 10 MGD facility (Table 3.3-18).

Total Costs: Estimated total costs for raw water, desalination, and concentrate disposal for water from the Dockum Aquifer with TDS of 1,500 mg/L range from $5.35 per 1,000 gallons for a 0.2 MGD facility, to $3.76 per 1,000 gallons for a 1 MGD facility, to $2.75 per 1,000 gallons for a 3 MGD facility, and $2.29 per 1,000 gallons for a 10 MGD facility (Table 3.3-18 and Figure 3.3-1). Estimated total costs for raw water, desalination, and concentrate disposal for water from the Dockum Aquifer with TDS of 3,000 mg/L range from$6.65 per 1,000 gallons for a 0.2 MGD facility, to $4.77 per 1,000 gallons for a 1 MGD facility, to $3.07 per 1,000 gallons for a 3 MGD facility, and $2.61 per 1,000 gallons for a 10 MGD facility (Table 3.3-18 and Figure 3.3-1). Estimated total costs for raw water, desalination, and concentrate disposal for water from the Dockum Aquifer with TDS of 5,000 mg/L range from $7.94 per 1,000 gallons for a 0.2 MGD facility, to $5.57 per 1,000 gallons for a 1 MGD facility, to $4.08 per 1,000 gallons for a 3 MGD facility, and $3.23 per 1,000 gallons for a 10 MGD facility (Table 3.3-18 and Figure 3.3-1). Estimated total costs for raw water, desalination, and concentrate disposal for water from the Dockum Aquifer with TDS of 20,000 mg/L range from $11.44 per 1,000 gallons for a 0.2 MGD facility, to $7.21 per 1,000 gallons for a 1 MGD facility, to $5.62 per 1,000 gallons for a 3 MGD facility, and $5.10 per 1,000 gallons for a 10 MGD facility (Table 3.3-18 and Figure 3.3-1).

Section 4
Regional Coordination of Regions A and O – Use of Video Conferencing to Facilitate Joint Meetings

In view of the fact that significant quantities of municipal water are obtained from areas of Region A to meet projected municipal needs in Region O, it is essential that the Llano Estacado Regional Water Planning Group and Panhandle Regional Water Planning Group coordinate and communicate regional water planning activities and work. However, given travel time and distances, plus the escalating cost of fuel, it is proposed that interactive video conferencing methods and facilities be evaluated as a means of facilitating coordination meetings of Regions A and O.

Interactive Video Conferencing Services Needed: Interactive Video Conferencing Services needed by Regions A and O are video conferencing equipped meeting rooms located conveniently to the locations of each regional water planning group; i.e.; a video conferencing room near or within Amarillo where the Region A Regional Water Planning Group meets, and an equivalent video conferencing room located in or near Lubbock where the Region O Regional Water Planning Group meets. Meeting rooms in each location need to be capable of seating up to approximately 60 persons, in order to accommodate regional planning group members, consultants, and the public.

Existing Interactive Video Conferencing Facilities/Services located conveniently to members of the Regions A and O Regional Planning Groups: The General Manager of the Llano Estacado Regional Water Planning Group's Administrative Agency, Mr. Jim Conkwright, and the Technical Consultant's Project Manager, Mr. Herbert Grubb located and made a personal call upon two Interactive Video Conferencing Facilities located in Lubbock. These two facilities were (1) AgriLife Research Facilities of the Texas A&M University System,[1] and (2) Texas Tech University. The AgriLife facility is located in two conference rooms and an auditorium. The conference rooms and the auditorium are each equipped with television cameras and viewing screens and the conference rooms can seat between 30 and 50 persons and the

[1] Personal interview and facilities demonstration by Jaroy Moore, Resident Director, Texas A&M Research and Extension Center, 1102 E FM 1294, Lubbock, Texas, 79403-6603.

auditorium can seat 80 persons. During the "visit" the facilities were demonstrated by connecting with similar facilities in the AgriLife Offices in Amarillo, Texas, the location of the Panhandle Regional Water Planning Group (Region A). At the Amarillo location, the video conference room can accommodate about 30, and is located about 50 yards from a meeting room which is large enough to accommodate the Region A Water Planning Group for an ordinary meeting.[2] The demonstration showed Mr. Conkwright and Mr. Grubb that the facilities would meet the needs of Regions A and O for coordinating meetings.

The Interactive Video Conferencing facilities at Texas Tech University are inside classrooms which can seat more than 40 persons, and although these facilities are available to outside groups, they are regularly used for classroom instruction. This, together with the fact that access to campus and limited parking would necessitate advanced reservations that would be difficult to meet the Regional Water Planning Groups' schedules.

The AgriLife Research Directors of the Texas A&M University System in Amarillo and Lubbock have indicated that the fully staffed Interactive Video

Interactive Video Conferencing Facilities	Location	Size	Cost
AgriLife Research	6500 Amarillo Blvd.W. Amarillo, Texas 79106 Phone: 806/677-5600	Seating for 30 persons	\$25 to \$50 per 4 hour session
AgriLife Research	1102 E. FM 1294 Lubbock, Texas 79403 Phone: (979) 862-2240	Seating for 30, 50, or 80 persons	\$25 to \$50 per 4 hour session

[2] Dr. John M. Sweeten, Resident Director, Texas A&M Research and Extension Center, 6500, Amarillo Blvd. W., Amarillo, Texas, 79106.

conferencing Facilities are available to Regions A and O, subject to scheduling in advance, and at costs of $25 to $50 per four hour session to groups such as Regional Water Planning Groups A and O.

Estimate costs of establishing and operating Interactive Video Conferencing Facilities/Services to meet the needs of Regions A and O: Representatives of commercial video conferencing providers have provided estimates of costs to establish Interactive Video Conferencing capabilities ranging from $12,000 to $15,000 per site to $15,000 to $25,000 per site.[3] In addition, each site must have staff that understand and can operate the video conferencing facilities and services. Neither Region A nor Region O has such staff available at this time.

Costs and services of Interactive Video Conferencing Facilities available from others in comparison to establishment of specialized services for Regions A and O:

Interactive video conferencing facilities and services are available at very low costs to Regions A and O, consequently it appears that justification can not be made at this time for the purchase and installation of such facilities. Instead, it is suggested that Regions A and O schedule an Interactive Video Conferencing meeting using the AgriLife Research facilities at Lubbock and Amarillo in order to test the functionality of Interactive Video Conferencing for interregional coordination. If the services available are satisfactory, then it will not be necessary to give further consideration to purchase and installation of such facilities. If the available services are not satisfactory, and Interactive Video Conferencing methods are found to be useful the regions, then further consideration can be given to the acquisition of such facilities.

[3] Great American Networking Conferencing, Harris, Scott, and AT&T, Adams, Andy.

Section 5
Summary and Conclusions

During 2006 and 2007, there have been announcements, with initiation of implementation, of three 110 million gallons per year capacity and one 50 million gallons per year capacity ethanol plants in the Llano Estacado Water Planning Region (Region O). In addition, there are regular announcements of new dairies being located in the water planning region. These are new industries for the region, for which water supplies have not been included in previous regional water plans for either the industries, the associated population that will supply the labor, nor the input support industries. The purposes of this study were to (1) estimate population and water demands for new ethanol plants and expanded numbers of dairies of the Llano Estacado Water Planning Region, (2) evaluate water supplies and desalination costs of Dockum Aquifer water, and (3) identify and describe video conferencing facilities available for coordination between Regions A and O. A summary of the results is presented below.

Ethanol Plants: As of 2008, two of the 110 million gallons per year ethanol plants are located at Hereford in Deaf Smith County, one 110 million gallons per year plant is located near Levelland in Hockley County and the 50 million gallons per year plant is located at Plainview in Hale County of the Llano Estacado Water Planning Region. The combined water requirements of these four plants are about 3.5 million gallons per day, or 3,920 acre-feet per year.

Dairies and Dairy Cattle: The number of dairies has grown from 37 in 2006 to 59 in 2008, the estimated number of dairy cattle has increased from about 55,000 in 2005 to 130,498 head in 2008, and milk production has increased from 4.14 million pounds per day in 2005 to 9.00 million pounds per day in March 2008. The projected number of head of dairy cattle in the eight-county area has been revised to 155,750 in 2010, 188,544 in 2020, and 280,714 head in 2060.

Water Demand Changes for Dairies: Water demand for dairies is projected to increase from about 6,256 acre-feet per year in 2010 to a revised projection of 8,374 acre-feet per year in 2010. For 2030, revised projections are 11,198 acre-feet per year compared to the 2006 Regional Water Plan projections of 11,427 acre-feet per year in 2030, and for 2060 are 15,093 acre-feet per year, compared to the 2006 Regional Water

Plan projection of 11,427 acre-feet per year in 2060. Revised projections of drinking water for dairy cattle and dairy milking parlor sanitation demands were based upon 48 gallons per cow per day instead of the 65 gallons per cow per day of the 2006 Regional Water Plan, and results in lower quantities of water demand for these purposes for the period of 2017 through 2033 than was projected for the 2006 Regional Water Plan, however, the revised projected water demand for dairies for 2060 is 15,093 acre-feet per year compared to the 2006 Water Plan projection of 11,587 acre-feet per year.

Water Demand Changes for Dairy Workers and Associated Population: In the case of municipal water demand, the increased dairy production is projected to result in a larger number of dairy workers and their associated family members, resulting in an increased municipal water demand of 466 acre-feet per year for the increased population of 2,405 in 2010, increased municipal demand of 182 acre-feet per year in 2020, and for 2060 an increased demand of 769 acre-feet per year for the increased projected population of 4,255.

Water Demands for Dairy Cattle Feed Production: The irrigation water requirements for feed production for the revised dairy projections are 16,938 acre-feet per year higher in 2010, 20,504 acre-feet per year higher in 2020, 25,019 acre-feet per year higher in 2040, and 30,528 acre-feet per year higher in 2060.

Increased Demand for Water for Ethanol Plants, Dairies, and Associated Population: The total increased water demand for ethanol production, dairies, dairy population and dairy feed production is 23,362 acre-feet per year in 2010, of which 16.7 percent is for ethanol production, 8.7 percent is for dairies, 2.0 percent is for dairy worker population, and 72.5 percent is for dairy feed production. The total is 30,166 acre-feet per year in 2040, and 38,723 acre-feet per year in 2060, of which ethanol production is 10.1 percent, dairies are 9.1 percent, dairy worker population is 1.98 percent, and dairy feed production is 78.8 percent.

Water Supply Potentials and Costs of Raw Water from the Dockum Aquifer: A potential supply of additional water in Bailey, Castro, Deaf Smith, Hale, and Parmer Counties is in the Dockum Aquifer which lies underneath the Ogallala Aquifer. The Dockum Aquifer has experienced little development except in areas where it is relatively shallow. Recharge to the Dockum in the study area consists of precipitation and streamflow losses in areas where the sediments are exposed at the land surface toward the northwest in New Mexico and Texas and downward leakage from the overlying Ogallala. The potential for a significant amount of recharge is extremely limited.

The best water bearing zone of the Dockum is sandstone in the lower part of the aquifer. Dockum wells in the vicinity of Hereford and in northeast Castro County typically are 800-950 ft deep. The deepest well depths would be about 1,400 ft in Lamb County. Typical well yields of Dockum wells is estimated to range from about 400 gpm in the Deaf Smith County area to about 200 gpm in the southern part of the study area. The salinity of water in the Deaf Smith County area typically ranges from concentrations of 800 to 1,500 milligrams per liter of total dissolved solids. In southern part of the study area, the salinity is greater than 20,000 mg/L of total dissolved solids.

It is estimated that there are nearly 85 million acre-feet of groundwater in the Dockum in this six county area, with the greatest amount of groundwater in storage with a salinity of 5,000 mg/L or less occurring in Deaf Smith County. Bailey and Lamb Counties have a considerable volume of Dockum groundwater, but the salinity is estimated to be mostly greater than 20,000 mg/L. Potential well field designs were prepared for two well fields (Deaf Smith and Parmer-Castro-Lamb County) and at three pumping rates (0.2, 1, 3, and 10 million gallons per day (MGD). The most economical water supply, not considering water treatment, was from the Deaf Smith well field pumping at a rate of 3 MGD. The delivery of raw water to a terminal near the well field is estimated to cost about $305 per acre foot.

Costs of Desalting Water from the Dockum Aquifer: Costs were estimated for desalination using Reverse Osmosis (RO) and concentrate disposal using solar evaporation and deep well injection for 0.2 MGD, 1 MGD, 3 MGD, and 10 MGD sized Dockum Aquifer well fields having 1,500, 3,000, 5,000, and 20,000 mg/L concentrations of TDS.

Desalination Costs: Estimated desalination costs for water with 1,500 mg/L range from $2.53 per 1,000 gallons for a .02 MGD facility, to $1.49 per 1,000 gallons for a 1 MGD facility, to $1.11 per 1,000 gallons for a 3 MGD facility, and $0.88 per 1,000 gallons for a 10 MGD facility. Estimated desalination costs for water with 3,000 mg/L range from $2.90 per 1,000 gallons for a .02 MGD facility, to $1.74 per 1,000 gallons for a 1 MGD facility, to $1.31 per 1,000 gallons for a 3 MGD facility, and $1.06 per 1,000 gallons for a 10 MGD facility. Estimated desalination costs for water with 5,000 mg/L range from $3.41 per 1,000 gallons for a .02 MGD facility, to $1.97 per 1,000 gallons for a 1 MGD facility, to $1.51 per 1,000 gallons for a 3 MGD facility, and $1.23 per 1,000 gallons for a 10 MGD facility. Estimated desalination costs for water with 20,000 mg/L range from $4.74 per 1,000 gallons for a .02 MGD facility, to $2.77 per 1,000 gallons for a 1 MGD facility, to $2.14 per 1,000 gallons for a 3 MGD facility, and $1.75 per 1,000 gallons for a 10 MGD facility.

Concentrate Disposal Costs using Solar Evaporation: Estimated concentrate disposal costs using solar evaporation for water with 1,500 mg/L range from $1.48 per 1,000 gallons for a 0.2 MGD facility, to $1.15 per 1,000 gallons for a 1 MGD facility, to $1.03 per 1,000 gallons for a 3 MGD facility, and $1.04 per 1,000 gallons for a 10 MGD facility. Estimated concentrate disposal costs using solar evaporation for water with 3,000 mg/L range from $2.41 per 1,000 gallons for a 0.2 MGD facility, to $1.91 per 1,000 gallons for a 1 MGD facility, to $1.79 per 1,000 gallons for a 3 MGD facility, and $1.72 per 1,000 gallons for a 10 MGD facility. Estimated concentrate disposal costs using solar evaporation for water with 5,000 mg/L range from $3.18 per 1,000 gallons for a 0.2 MGD facility, to $2.63 per 1,000 gallons for a 1 MGD facility, to $2.44 per 1,000 gallons for a 3 MGD facility, and $2.38 per 1,000 gallons for a 10 MGD facility. Estimated concentrate disposal costs using solar evaporation for water with 20,000 mg/L range from $5.30 per 1,000 gallons for a 0.2 MGD facility, to $4.75 per 1,000 gallons for a 1 MGD facility, to $4.45 per 1,000 gallons for a 3 MGD facility, and $4.27 per 1,000 gallons for a 10 MGD facility.

Concentrate Disposal Costs using Deep Well Injection: Estimated concentrate disposal costs using deep well injection for water with 1,500 mg/L range from $9.75 per 1,000 gallons for a 0.2 MGD facility, to $2.03 per 1,000 gallons for a 1 MGD facility, to $0.71 per 1,000 gallons for a 3 MGD facility, and $0.44 per 1,000 gallons for a 10 MGD facility. Estimated concentrate disposal costs using deep well injection for water with 3,000 mg/L range from $10.63 per 1,000 gallons for a 0.2 MGD facility, to $2.22 per 1,000 gallons for a 1 MGD facility, to $0.83 per 1,000 gallons for a 3 MGD facility, and $0.59 per 1,000 gallons for a 10 MGD facility. Estimated concentrate disposal costs using deep well injection for water with 5,000 mg/L range from $11.47 per 1,000 gallons for a 0.2 MGD facility, to $2.48 per 1,000 gallons for a 1 MGD facility, to $1.64 per 1,000 gallons for a 3 MGD facility, and $1.04 per 1,000 gallons for a 10 MGD facility. Estimated concentrate disposal costs using deep well injection for water with 20,000 mg/L range from $13.98 per 1,000 gallons for a 0.2 MGD facility, to $3.01 per 1,000 gallons for a 1 MGD facility, to $2.12 per 1,000 gallons for a 3 MGD facility, and $1.88 per 1,000 gallons for a 10 MGD facility.

Estimated Total Costs of Water from the Dockum Aquifer: Estimated total costs for raw water, desalination, and concentrate disposal for water from the Dockum Aquifer with TDS of 1,500 mg/L range from $5.35 per 1,000 gallons for a 0.2 MGD size facility, to $3.76 per 1,000 gallons for a 1 MGD facility, to $2.75 per 1,000 gallons for a 3 MGD facility, and $2.29 per 1,000 gallons for a 10 MGD facility. Estimated total costs for raw water, desalination, and concentrate disposal for water from the Dockum Aquifer with TDS of 3,000 mg/L range from $6.65 per 1,000 gallons for a 0.2 MGD size facility, to $4.77 per 1,000 gallons for a 1 MGD facility, to $3.07 per 1,000 gallons for a 3 MGD facility, and $2.61 per 1,000 gallons for a 10 MGD facility. Estimated total costs for raw water, desalination, and concentrate disposal for water from the Dockum Aquifer with TDS of 5,000 mg/L range from $7.94 per 1,000 gallons for a 0.2 MGD size facility, to $5.57 per 1,000 gallons for a 1 MGD facility, to $4.08 per 1,000 gallons for a 3 MGD facility, and $3.23 per 1,000 gallons for a 10 MGD facility. Estimated total costs for raw water, desalination, and concentrate disposal for water from the Dockum Aquifer with TDS of 20,000 mg/L range from $11.44 per 1,000 gallons for a 0.2 MGD size facility, $7.21 per 1,000 gallons for a 1 MGD facility, to $5.62 per 1,000 gallons for a 3 MGD facility, and $5.10 per 1,000 gallons for a 10 MGD facility.

Interactive Video Conferencing Facilities: Fully staffed interactive video conferencing facilities and services, with capabilities to meet the needs of Regions A and O are in existence and are available to both Regions A and O at Offices of the AgriLife Research Facilities of the Texas A&M University System in Amarillo and Lubbock, respectively. Consequently it appears that justification can not be made at this time for the purchase and installation of such facilities. It is suggested that Regions A and O schedule an Interactive Video Conferencing demonstration using the AgriLife Research facilities at Lubbock and Amarillo in order to test the functionality of Interactive Video Conferencing for interregional coordination. If the services available are satisfactory, then it will not be necessary to give further consideration to purchase and installation of such facilities.

Conclusions: The revised projections of water demand for the ethanol and expanded dairy water using sectors, as presented in this report, are available for use in development of the 2011 Llano Estacado Regional Water. The results of the Dockum Aquifer water supply and desalt cost analyses provide information as to potential sources, quantities, and costs of water for consideration in the development of water management strategies to meet some local municipal and industrial needs.

Interactive videoconferencing services are readily available, at negligible costs, for use by Regions A and O for coordination of regional water planning.

Section 6
Adoption of Report

6.1 Llano Estacado Regional Water Planning Group Meetings and Actions

This report was prepared in accordance with the approved Scope of Work pursuant to TWDB Contract No. 0704830700. At its August 31, 2006 public meeting, the Llano Estacado Regional Water Planning Group (LERWPG) approved the Scope of Work and authorized the High Plains Underground Water Conservation District (HPUWCD) to submit an application to the Texas Water Development Board (TWDB) for grant funding. At its February 21, 2008 public meeting, the draft of Section 1 "Estimates of Population and Water Demands for New Ethanol Industries and Expanding Dairies," and Section 2 "Evaluation of Water Supplies from the Dockum Aquifer in Bailey, Castro, Deaf Smith, Hale, Lamb, and Parmer Counties" was presented to the LERWPG and the Public for review and comments.

At its October 23, 2008 public meeting, the draft of the Regional Water Planning Report containing Section 1, entitled "Background and Introduction, Section 2, entitled "Estimates of Population and Water Demands for New Ethanol Industries and Expanding Dairies," Section 3 entitled "Evaluation of Water Supplies and Desalination Costs of Dockum Aquifer Water," Section 4 entitled "Regional Coordination of Regions A and O – Use of Video Conferencing to Facilitate Joint Meetings," and Section 5 entitled "Summary and Conclusions" was presented to the LERWPG for review and comment. At its October 23, 2008 public meeting, the LERWPG approved the draft report and directed the HPUWCD to submit the draft report to the TWDB for review. All draft report comments were addressed, and the draft report was submitted by the HPUWCD to the TWDB on December 3, 2008. At its April 23, 2009 public meeting, the LERWPG approved responses to the TWDB review comments and directed the HPUWCD to submit the final report to the TWDB by April 20, 2009.

6.2 Texas Water Development Board Comments and LERWPG Responses -- Contract No. 0704830700

Region O, Region-Specific Contract Studies 1-3

1) **Population and Water Demand**
2) **Evaluation of Water Supplies from the Dockum Aquifer**
3) **Coordination of Regions A and O**

TWDB Comments on Draft Final Region-Specific Study Reports

General Comments

These comments pertain to the entire report since the three region-specific studies are bound in one report and the chapter numbers do not correspond with the task numbers (studies 1-3).

1. Please consider revising the title of the report to indicate that it includes three region-specific studies and what each study focused on.
   Response: The title has been expanded to include the following wording "Estimates of Population and Water Demands for New Ethanol Industries and Expanding Dairies; Evaluation of Water Supplies and Desalination Costs of Dockum Aquifer Water, and Video Conferencing Facilities Available for Coordination Between Regions A and O."

2. Please submit all data, maps, and functioning analytic models in an electronic format along with the final report as required by the contract between TWDB and Region O.
   Response: Data, Maps, and Analytic Models developed during the study will be submitted to TWDB, as required in the contract.

3. In the Executive Summary and Section 5, please consider indicating the conclusions associated with each of the region-specific studies. As written, it is difficult to identify specific conclusions associated with each study.
   Response: The conclusions of each Section are presented in Section 5 and the Executive Summary.

Region-Specific Study 1, Population and Water Demand

1. Due to the increased dairy and ethanol production, the report also recommends increasing population and water demand projections to support additional labor needed to operate new facilities and supporting businesses in certain counties. Recommended revisions to county projections range from 2,405 persons in 2010 to 4,255 in 2060. While the reasoning behind these recommended increases is valid and well presented, a comparison of TWDB projections in the 2006 regional plan (based on 2000 Census data) and historical county population estimates from the Texas State Data Center (TSDC) show that recent and current estimates are less than the original TWDB projections. For example, for 2010 the report recommends an increase of 336 people in Bailey County, and the TWDB projection is higher than the 2007 TSDC estimate by 414 individuals for that county. In total, for all counties with revised projections, TWDB projections exceed TSDC estimates by 11,140 in 2007 and requested increases to population forecasts recommended in the report total only 2,405. Thus, the TWDB staff does not recommend that Region O request revisions to the TWDB's 2006 population and municipal water demand projections.

Response: As stated, TSDC data show population declines for the Region O Counties since year 2000. In addition, enrollment in nearly all of the Independent School Districts of Region O, as reported by Education Intelligence Agency, has declined during the period 2000-2001 to 2005-2006. Thus, it appears that expanding employment in the Dairy and Ethanol Industries of the region are somewhat offsetting population declines, as reported by the TSDC, and do not indicate that the LERWPG should revise the population and water demand projections for use in regional water planning.

2. The contract scope of work and the objectives included in Section 1 of the report state that additional population and quantities of municipal water will be estimated for the listed counties, including cities in each county. Since the report only provides estimates for counties, please include the estimates for cities in each county.
   Response: The populations involved are a part of the agricultural labor force for which data are not available with which to indicated city of "residence."

3. TWDB's acceptance of the final report does not constitute approval of any revised population or water demand projections contained therein. The formal procedure for requesting revised projections is stated in TAC 357.5 (d) (2): "Before requesting a revision to the population and water demand projections, the regional water planning group shall discuss the issue at a public meeting for which notice has been posted pursuant to the Open Meetings Act in addition to being published on the internet and mailed at least 14 days before the meeting to every person or entity that has requested notice of regional water planning group activities. The public will be able to submit oral or written comment at the meeting and written comments for 14 days following the meeting. The regional water planning group will summarize the public comments received in its request for projection revisions. Within 45 days of receipt of a request from a regional water planning group for revision of population or water demand projections, the executive administrator shall consult with the requesting regional water planning group and respond to their request."

   All requested revisions which are approved following consultation with the Texas Department of Agriculture, Texas Commission on Environmental Quality, and Texas Parks and Wildlife Department, will then be presented for consideration of Board approval at the next scheduled meeting.
   Response: The LERWPG notes this comment, and will proceed accordingly (Please see response to Number 1 above).

Region-Specific Study 2, Groundwater Availability from the Dockum Aquifer

1. In section 3.1 (Groundwater Availability from the Dockum Aquifer, page 3-2, paragraph 1, line 1), please add Lamb County to the list of counties.
   Response: Lamb County has been added, as requested.

2. In section 3.1.1 (Hydrogeologic Framework of Dockum), page 3-6, please provide the reference for McGowen and others (1977).
   Response: A footnote has been added to provide the reference.

3. Please correct the spelling of *Herford* to the correct spelling (*Hereford)* throughout the report.
   Response: The spelling of Hereford has been corrected.

4. In section 3.1.6.4 (Estimated Quantity of Production and Drawdown), page 3-26, paragraph 2, lines 4-5, please explain why the salinity of produced water in the Deaf Smith County well field is expected to be in the 5,000 to 8,000 mg/l TDS range. Data, albeit limited, shows the TDS in Deaf Smith County is less than 5,000 mg/l (see pages 3-19 and 3-21).
Response: In the vicinity of the Deaf Smith potential well field, the data (Figures 3.1-13 and 3.1-15) of the report indicate a rapid transition from saline to very saline waters. Therefore, it was decided to be on the "conservative side" and base the analyses upon salinities in the 5,000 mg/L to 8,000 mg/L instead of 3,000 mg/L to 5,000 mg/L.

5. In section 3.3.2.2 (Deep Well Injection – Methods and Costs), page 3-50, reference in footnote, please correct the reference to *Mace and others, 2006, Please pass the salt: using oil fields for the disposal of concentrate from desalination plants, TWDB Report 366, 198 p.*
Response: The reference has been added.

6. The contract scope of work indicates that cost estimates would be developed for desalination plants ranging capacity from 0.2 to 2 MGD, while the report presents cost estimates for 1, 3, and 10 MGD plants. Please provide the rationale for the selected plant capacities and variance from the contract scope of work.
Response: An analysis was added for a desalt plant capacity of 0.2 MGD. Plant sizes were selected to provide information for applicable ranges of needs of industrial and municipal water users, and to test and illustrate the potentials for economies of sizes of facilities to lower unit cost of desalted water.

Region-Specific Study 3, Coordination of Regions A and O

1. The contract scope of work item 3 B states that Region O will identify and survey interactive video conferencing facilities, including Region A Planning Group entities and Texas Tech. Please list or otherwise include the results of the survey in the final report. In addition, item 3 B further states "the nature of this work will be descriptive in terms of facility locations, capabilities, costs, and other information found to be pertinent". Please consider including a table summarizing the details of the facilities found so that Regions A and O can better compare the facilities, including the services and costs of each.
Response: Additional information and explanations have been added, as suggested.

Appendix

Letter from Texas Association of Dairymen With Enclosures "Crop Use for Dairy Production in Region O" And "Projected Dairy Water Use, Region O"

Texas Association of Dairymen

April 28, 2008

Dr. Melanie Barnes
Texas Tech University

Dr. Don Ethridge
Texas Tech University

Re: Summary Crop Use for Dairy Production in Region O

Dear Dr. Barnes and Dr. Ethridge,

Please find the completed projections for dairy cow populations in Region O which Dr. Ellen Jordan and TAD has compiled. I believe the data will provide you with the information based on our survey of dairies in Region O. I will bring several copies of this data with me to the meeting.

I have made plans to join you on May 1st in Lubbock. Dr. Jordan, due to prior meetings, will be in Amarillo that day and unable to join the group in Lubbock. If you have any questions for Dr. Jordan prior to the meeting, please let her or myself know, and we will try to address them.

I do appreciate the opportunity to work with your committee and the planning group on these matters.

Sincerely,

John Cowan

John Cowan
Executive Director
Texas Association of Dairymen

3500 William D. Tate Ave., Suite 100 – Grapevine Texas 76051-8734
Tel: 817-410-4576 – Fax: 817-410-4541

Crop Use for Dairy Production in Region O

1. We have completed the projections for cow populations in Region O with either 0, 1 or 3% growth starting in 2020. The most probable scenario based upon historical growth patterns in other states is that growth would continue at the 1% level after 2020, consequently that scenario will be used in the projections which follow. These projections result in 8 counties (Bailey, Castro, Deaf Smith, Hale, Lamb, Lubbock, Parmer, and Terry) in which we actually predict dairy operations will be built. These data were submitted previously to you.

2. Based on historical land purchase patterns of the dairies and the predictions, we compiled the average irrigated acreage of corn, sorghum, wheat, and cotton grown in counties using the 1995-2007 NASS databases (cotton is not yet available for 2007, so an 11 year average will be calculated for cotton). We used the planted acres versus the harvested acres, assuming that if the producer planted a crop they thought they had enough water to make a crop. There are a variety of reasons from hail and wind damage to drought to government programs that could have influenced these numbers, however insufficient time and resources to develop a model to factor in all these items was not available.

Table 1: Average irrigated acres of total production in Bailey, Castro, Deaf Smith, Hale, Lamb, Lubbock, Parmer, and Terry Counties from 1995 through 2007 compiled from NASS data files for cotton, sorghum, corn and wheat, including the average production per crop. (Alfalfa data was not available from the NASS database.

Practice	Year	Region O Projected Dairy Counties	Alfalfa	Cotton* Planted All Purposes	Sorghum Planted All Purposes	Corn Planted All Purposes	Wheat Planted All Purposes	Total Acres
Irrigated	1995	8 Co Total		879500	135700	367300	245800	
Irrigated	1996	8 Co Total		876800	185500	418400	255900	
Irrigated	1997	8 Co Total		832700	155700	397900	285100	
Irrigated	1998	8 Co Total		838200	99700	403800	244400	
Irrigated	1999	8 Co Total		965000	193700	264500	253100	
Irrigated	2000	8 Co Total		1051300	105000	261700	296300	
Irrigated	2001	8 Co Total		913500	172900	185700	342500	
Irrigated	2002	8 Co Total		913900	174500	186600	435000	
Irrigated	2003	8 Co Total		942600	364100	189000	393300	
Irrigated	2004	8 Co Total		917400	91600	214000	393500	
Irrigated	2005	8 Co Total		888800	188100	235200	312600	
Irrigated	2006	8 Co Total		812900	107900	225500	343600	
	2007	8 Co Total		NA	251000	348300	379200	
Irrigated	Mean			902716.7	171184.6	284453.8	321561.5	1679917
Irrigated	StDev			65045.42	74120.86	89542.91	64663.34	
	%			54%	10%	17%	19%	

*Mean, StDev and % were determined based on 11 crop years since 2007 information was not available in NASS database.

3. After determining the average production per crop for the 8 counties, we then utilized the % of each crop grown and used that percentage to determine an average irrigation rate of 14.5 inches of water on the 1,679,917 acres of average annual acres. The water use per acre from the Extension budgets is as follows:
   Wheat – 15 acre inches
   Sorghum, grain – 14 acre inches
   Sorghum, silage – 13 acre inches
   Cotton – 12 acre inches
   Corn Silage – 22 acre inches
   Corn, grain – 22 acre inches
   Alfalfa – 24 acre inches

   Unfortunately the NASS data did not have alfalfa acreage by county, so we can not account for the acreages that were in Region O prior to the influx of dairies for that commodity, therefore the 0 acreage is an underestimate and results in the maximum water utilization possible.

4. Next we calculated the average acre inches required by the crops grown for dairy, using the above Extension budget irrigation rates, as 16.1 inches of water on the acreage used to grow forages for dairy. In general, dairy operations have been sited based on water availability for the crops they have grown so less change in water use may be required than is predicted using this method of estimation. Conversely the dairies do drill additional wells to insure that they can pump sufficient water to grow the forages required for their herds even during periods of low rainfall instead of allowing the land to become "unharvested" cropland.

5. *For more accurate long range planning, additional data should be collected on the requirements to grow silage meeting the nutrient requirements for dairy rations compared to a grain crop. For example when dairies make wheat silage they want to harvest a more immature crop to increase nutritional value and means watering halts in April. The feedlots may look to more mature silage and would continue the watering process further as they are looking for a concentrated source of the fiber from this forage and are obtaining more of their digestible energy from concentrates. Dairies want to have highly digestible forages to obtain some of their digestible energy from the forages as well as it serving as a fiber source. Many feedlot rations will be 10% forage where dairy rations are 40-60% forages; consequently the forage quality requirements are quite different.* ***Thus the Extension irrigation budgets should be re-evaluated to quantify the differences in irrigation requirements for silages grown for dairies relative to crops grown for grain.*** *Our producers estimate that they are using at least 10% less water for their silages than if they would grow that crop to grain harvest.*

6. Once the average acre inches of irrigation needed by the crops required for the forages utilized in dairy cattle rations was calculated, the estimated difference

required to grow crops for dairy compared to the traditional pattern of crop production is 1.6 inches. We realize that future crop production patterns may vary significantly from historical trends as crop farmers constantly re-evaluate the economic return potential from the crops that they can grow and alter their plans based on price, water availability, government programs, etc.

For example: In 2007, there were nearly 64,000 more acres of corn grown than during the 12 year average, which means nearly 640,000 additional acre inches of water were used than if that acreage had remained in cotton or 512,000 acre inches if it had previously been in sorghum grain production.

7. Finally how the water use for dairy cropping schemes would vary from that of the traditional cropping pattern was calculated out to 2060. The total number of cows (using the 1% growth rate after 2020) the acreage required to provide forage for these animals (including the heifers associated with them), the total irrigation required to grow those crops, and the irrigation required above traditional cropping patterns is presented in Table 1. Figure 2 represents the increased irrigation required for dairy relative to the average irrigation used for cropping in the 8 county region during the 1995-2008. Finally Figure 3 illustrates how the increased water use calculated for dairy farm forage production may be masked by producer decisions to change cropping patterns for other reasons using the increased water usage for corn grown in 2007 discussed previously as an example.

Table 1: Based on 1% growth in the dairy herd after 2020, the total number of crop production acres required to produce the forage needed for dairy as well as the total irrigation water and the difference in water required above traditional cropping patterns.

Year	Total Cows	Acres for Dairy	Total Irrigation		Above Traditional Cropping Pattern	
			Acre In	Acre Feet	Acre In	Acre Feet
2008	130,498	113,533	1,827,885	152,324	170,300	14,192
2010	155,750	135,503	2,181,590	181,799	203,254	16,938
2020	188,544	164,033	2,640,936	220,078	246,050	20,504
2030	208,270	181,195	2,917,238	243,103	271,792	22,649
2040	230,060	200,152	3,222,450	268,538	300,228	25,019
2050	254,129	221,092	3,559,585	296,632	331,638	27,637
2060	280,716	244,223	3,931,989	327,666	366,334	30,528

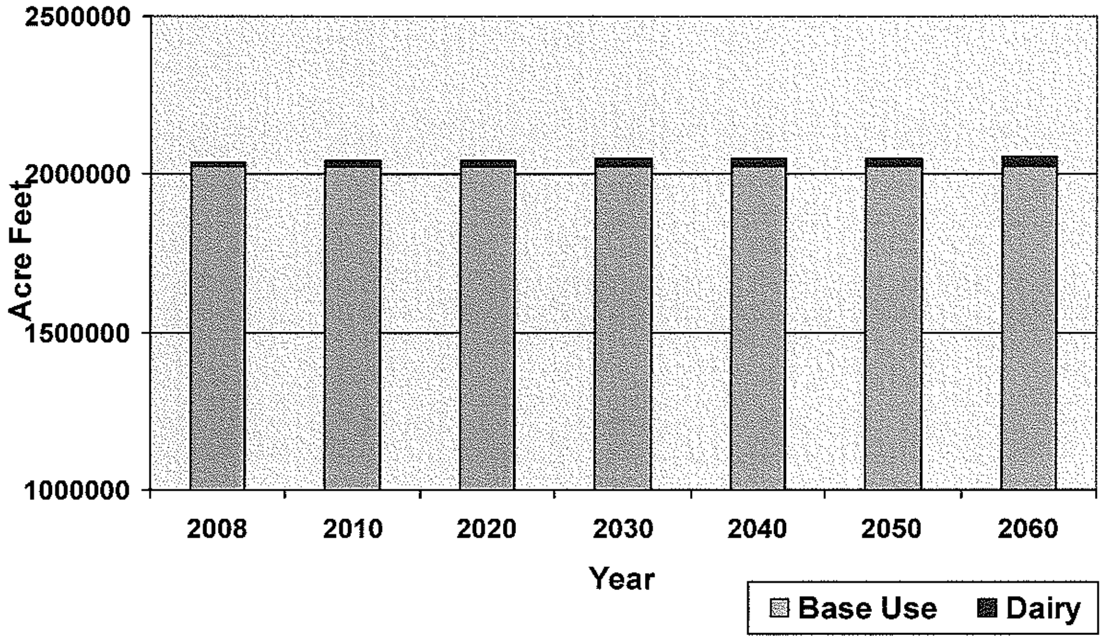


Figure 1: Total acre feet of water use if average crop production from 1995 to 2007 is maintained with the inclusion of water for dairy at the 1% growth rate after 2020.

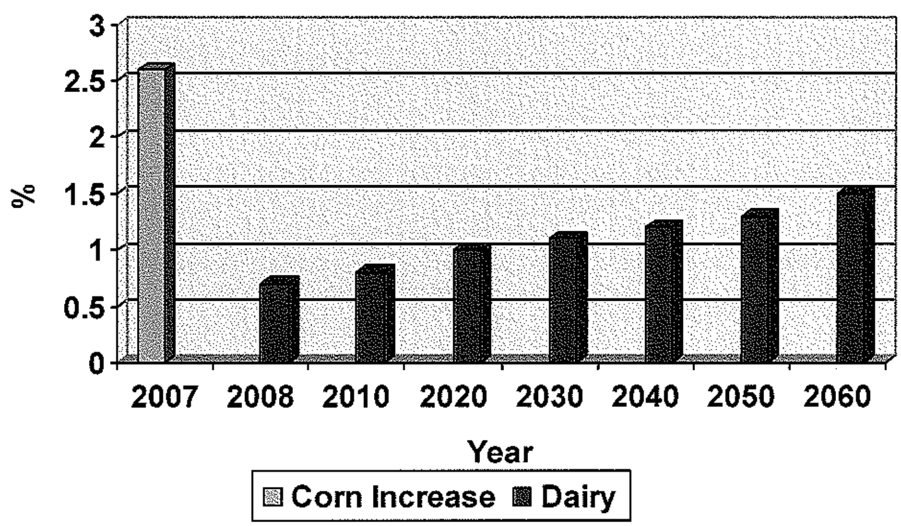


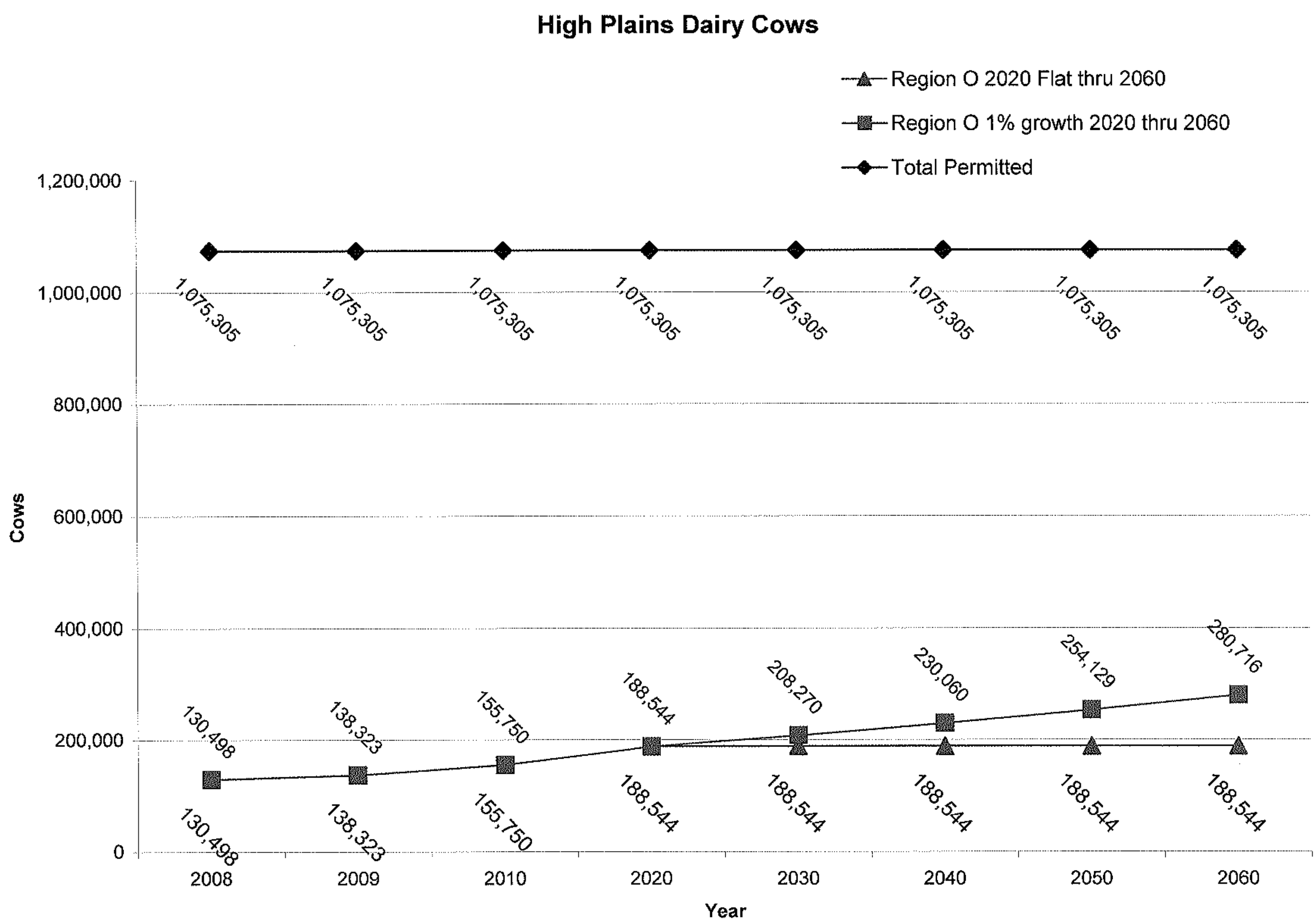
Figure 2: Comparison of the % of water use for the additional irrigation water required by crops grown for dairy relative to the water use of the average crop acreage from 1995-2007 and in comparison to the additional water used on the 64,000 corn acres harvested in 2007 compared to the average annual production, if the acres were switched from cotton production.

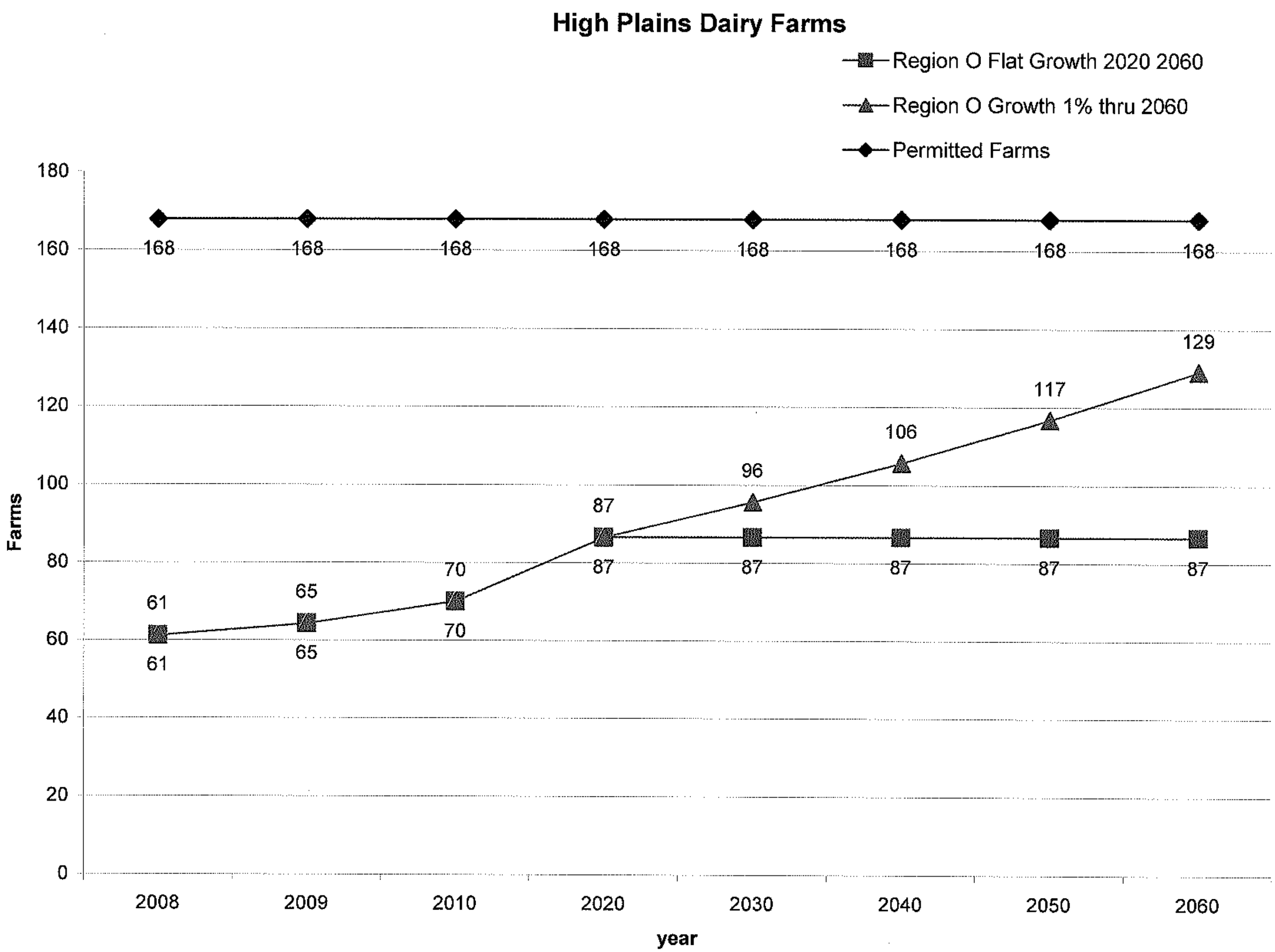
8. We have provided this data on the 8 county basis, not by individual county since this is a regional plan and some of these crops are bought and sold across county lines. By aggregating the counties, the differences in the water use patterns within the various counties are accounted for and the way the water use changes for the region was predicted.

Region O Dairy Farm / Cows Projections of TAD

		Projected Growth of Dairy Farms / Cows Region O High Plains Texas															
		2,008		2,009		2,010		2,020		2,030		2,040		2,050		2060	
	County	Feb 08 Farms	Feb 08 Cows	Farms	Cows	Farms	Cows	Farms	Cows	Farms	Cows	Farms	Cows	Farms	Cows	Farms	Cows
O	BAILEY	9	15,218	10	18,000	11	24,700	13	32,120	14	35,480	16	39,193	18	43,293	19	47,822
O	BRISCO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O	CASTRO	10	23,082	11	26,000	11	27,450	14	35,700	15	39,435	17	43,561	19	48,118	21	53,152
O	COCHRAN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O	DEAF SMITH	13	26,800	13	26,800	14	29,000	18	34,000	20	37,557	22	41,486	24	45,827	27	50,621
O	FLOYD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O	HALE	5	13,531	6	15,900	6	15,900	7	17,850	8	19,718	9	21,780	9	24,059	10	26,576
O	HOCKLEY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O	LAMB	9	17,876	10	20,000	11	24,000	13	26,000	14	28,720	16	31,725	18	35,044	19	38,710
O	LUBBOCK*	1	1,500	1	1,553	1	1,600	1	2,089	2	2,308	2	2,549	2	2,816	2	3,110
O	PARMER	13	30,491	14	28,000	15	31,000	19	38,000	21	41,976	23	46,367	26	51,218	28	56,577
O	SWISHER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O	TERRY*	1	2,000	1	2,070	1	2,100	1	2,785	2	3,076	2	3,398	2	3,754	2	4,146
	Total Reg O	61	130,498	65	138,323	70	155,750	87	188,544	96	208,270	106	230,060	117	254,129	129	280,716

TAD data April 2008, resource data supplied from Federal Milk Market and Industry Cooperative Marketing Analysis


High Plains Dairy Cows
Region O 2020 Flat thru 2060
Region O 1% growth 2020 thru 2060
Total Permitted
Cows
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
1,075,305
1,075,305
1,075,305
1,075,305
1,075,305
1,075,305
1,075,305
1,075,305
130,498
138,323
155,750
188,544
208,270
230,060
254,129
280,716
130,498
138,323
155,750
188,544
188,544
188,544
188,544
188,544
2008
2009
2010
2020
2030
2040
2050
2060
Year


High Plains Dairy Farms
Region O Flat Growth 2020 2060
Region O Growth 1% thru 2060
Permitted Farms
Farms
180
160
140
120
100
80
60
40
20
0
2008
2009
2010
2020
2030
2040
2050
2060
year
168
168
168
168
168
168
168
168
61
65
70
87
96
106
117
129
61
65
70
87
87
87
87
87

Projected Dairy Water Use, Region O

Year

	2007	2010	2020	2030	2040	2050	2060
# of Cows	118,948	147,599	188,544	208,270	230,060	254,129	280,716
Water for drinking, cleanup							
ac. In.	75,467	93,645	119,623	131,210	144,938	160,101	176,851
ac. Ft.	6,289	7,806	9,969	10,934	12,078	13,342	14,738
Additional water for forages							
ac. In.	170,300	203,254	146,050	271,792	300,228	331,638	366,334
ac. Ft.	14,172	16,438	20,504	22,649	25,019	27,637	30,528
Net use increase							
ac. In.	245,767	296,899	265,673	403,002	445,166	491,739	543,185
ac. Ft.	20,461	24,244	30,473	33,583	37,097	40,979	45,266

as compared to cotton

Dairy No's.
Calc. @ 1%/yr. growth -

high 30's to 45 gpd/cow

65-75# milk/da./cow

1 load = 6,000 gal. or 50,000#

80 loads per day from here to Ala/SE. USA
Walhart area going to NY

57% of total dairy ration is forage

Llano Estacado
Regional Water Planning Group (Region O)
2011 Regional Water Plan
Phase I Report

1. **Estimates of Population and Water Demands for New Ethanol Industries and Expanding Dairies;**

2. **Evaluation of Water Supplies and Desalination Costs of Dockum Aquifer Water; and**

3. **Video Conferencing Facilities Available for Coordination Between Regions A and O.**

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Mr. Doug Hutcheson, Sec./Treas.
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Public

The Honorable Jim Barron
County Governments

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Agriculture

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Agriculture

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Agriculture

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River Authorities

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Mr. E. W. (Gene) Montgomery
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